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BOLT BERANEK AND NEWMAN INC

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Report No. 949
Job No. 110072

STUDIES OF TEMPORARY THRESHOLD SHIFT
CAUSED BY HIGH INTENSITY ACOUSTIC TRANSIENTS

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20 August 1962

Submitted to:

Research and Development Division
Office of the Surgeon General
Department of the Army
Washington 25, D. C.

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20 August 1962

Norman L. Carter and Karl D. Kryter

Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge 38, Massachusetts

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3. Principal Investigators: Norman Carter and Karl D. Kryter

4. Number of Pages, Illustrations and Date: 18 pages, 2 tables,
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5. Contract Number: DA-49-007-MD-985

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as a function of the susceptability of different people to
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experiments on the effects of rise time should provide the basis
for establishing a general description of the effects of gun noise
on auditory fatigue. This description should provide the means
for specifying the noise characteristics of weapons and opera-
tional procedures for their use with respect to protection of the
hearing of military personnel.

The great variability in the susceptibility of different persons to impulses, probably due to variations in the behavior of the auditory reflex, suggests that damage risk criteria for impulse noise must be designed to protect those persons with ears far more sensitive than those possessed by the average person. Individual differences in susceptibility to auditory fatigue are much greater for impulse than for steady state noise.

One of the experiments conducted revealed that persons susceptible to auditory fatigue from impulse noise were not necessarily more or less susceptible to steady state noise.

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INTRODUCTION

The present series of experiments follow from a preliminary
study described in BBN Report No. 916[1]. That study, now
called Experiment I, was concerned with the effect of pulse
repetition rate (pulses per second) and the number of pulses
upon thresholds for pure tones in the frequency range of 2500
to 10000 cps. Each pulse had a triangular acoustic waveform,
with a rise time of 0.5 millisecond, duration 1 millisecond
and peak sound pressure level 168 db re .0002 microbar.
Pulse rates used were 1, 5, 10, 20, 40 and 80 pulses per sec-
ond (PPS). The numbers of pulses were 5, 10, 20, 40 and 80.

That study allowed the following tentative conclusions:
(1) the frequency of maximum loss is in the region of 4000-
5000 cps; (2) the repetition rate most likely to produce
temporary threshold shift was 1 PPS; and (3) the TTS increased
with the number of pulses.

One feature of the results was that even though the hearing
losses were for the most part small and unreliable, there was
no doubt that those moderately large losses that did take place
were "real" and not artifacts of the hearing tests. It was

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supposed that the explanation for this might be that people
have "thresholds" for acoustic trauma similar to absolute
thresholds for hearing, and that apart from day to day varia-
tions in the ear there is an "acoustic trauma threshold value"
of X number of pulses for each person (assuming other relevant
parameters such as repetition rate, peak to peak level, rise
time, etc., are constant). If this were true the variability in
the results of Experiment I could be due to the characteristics
of the particular subjects involved as well as the particular
values of rise time, duration, repetition rate, number of pulses
and peak to peak level that were used.

The assumption of an acoustic trauma threshold for pulses also
implies that once this threshold is reached, TTS will show the
same function of number of pulses for all normal ears, regard-
less of their particular ATT values.* If this is so, then
prolonged and expensive experimentation would be avoided by
selecting subjects from the low end of the ATT continuum.

---

*In this discussion the type of function of TTS above ATT for
any parameter had not been mentioned. It may be continuous or
a step function (e.g., 0 db to X db TTS) for any parameter.
This and other experimental problems, such as the relation of
ATT to other auditory thresholds, are considered in experi-
ments reported below.

EXPERIMENT II

Cursory examination of the data of Experiment I suggested that
an average of one out of four normal hearing young adults could
be expected to show moderate hearing losses (over 20 db) 30 sec-
onds to two minutes after exposure to 80 triangular acoustic
pulses (0.5 millisecond rise time, 1 millisecond duration, 168 db
peak to peak) at a repetition rate of 1 PPS. Accordingly it
was anticipated that if such an exposure were given to 60 col-
lege students 15 of them would show losses greater than 20 db.
Caution dictated, however, that in the present context, where
large numbers of subjects are involved and the range of sensi-
tivity to this stimulus is unknown, subjects should first be
exposed to 40 pulses only, at lower peak to peak levels. The
number of pulses, and possibly their level, could then be in-
creased for those subjects showing no significant threshold
shift, until a criterion (say, 10 db TTS) was reached.

Apparatus and Procedure

The apparatus used in generating the acoustic stimuli has been
described in detail in a previous report.[2] It consisted of an
arbitrary function generator, or photoformer, capable of gener-
ating any desired electrical waveform (voltage by time), an
amplifier for amplifying and controlling the peak voltage and
a small, high intensity loudspeaker (KLH 6.5) mounted on a
headband and held firmly against the subject's head during
exposure. The level of the acoustic pulse was measured by
placing the earphone on a dummy head with a microphone (Altec 21
BR 200) in the simulated ear canal and leading the output of
the microphone to an oscilloscope (Dumont type 304 AR). The
vertical axis of this scope was previously calibrated using a
BBN acoustic calibrator (308-C-3). The rise time and duration
of the pulse were read off the scope in a similar way, after

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calibrating the horizontal axis with a 1000 cps sine wave.
Photographs of the photoformer mask, electrical output of the
amplifier, and the acoustic pulse as shown on the oscilloscope
are presented in Fig. 1.

Hearing losses were measured by a subject-operated Bekesy audio-
meter (Grason Stadler type E-800). As in Experiment I tests were
made before and after exposure, but it was decided to drop the
method of recording hearing losses in terms of a single "loss
number" as was done for Experiment I, in favor of the usual
method of db threshold shift at each test frequency.

Test frequencies were 2000, 4000, 8000 and 500 cps, tested in
that order for 30 seconds each, before and after exposure. The
first frequency tested after the train of high intensity pulses
was 2000 cps, begun 30 seconds post exposure. As is usual in
this type of pure tone threshold, audiometry threshold at any
frequency was the average of the midpoints of the excursions
over the time the frequency was tested.

Forty-five normal hearing college students (29 male, 16 female)
were exposed to the acoustic transients in the sequence, and at
the levels indicated in Table 1. In some instances the pure
tone thresholds were tested a second time after exposure. This
generally indicated that the losses were "real" and not due to
some artifact connected with the subject's inexperience with
audiometry.

Results

The results presented in Table 1 confirm that there is a con-
siderable range in the susceptibility of young adult subjects
to TTS induced by this type of "impulse" noise. Large individ-
ual differences in susceptibility to impulse noise can also be

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seen in Fig. 2 where for the 45 subjects we have plotted the
distribution of thresholds following exposure to impulse noise
and the distribution of pre-exposure thresholds. Similiar vari-
ability among subjects with respect to their susceptibility to
auditory fatigue from acoustic impulses was found by Ward et al[3].

The second aim of this experiment was to select subjects for
later work. Eighteen of the 45 subjects of Table 1 show a greater
than 10 db loss at one or more frequencies following 120 pulses
(or less) of 168 db peak to peak (or lower). These subjects are
indicated by an asterisk; the initialled numbers are the subjects
who proved available for the later experiments.

EXPERIMENT III

Experiment I indicated, as might be expected, that TTS increased
as a function of the number of pulses. The present study was
intended to get quantitative data on the shape of this function.

Apparatus and Procedure

The apparatus for producing the stimuli and determining pure
tone thresholds was identical with that used in the Experiment II
condition. Rise time of the pulses was again 0.5 millisecond,
duration 1.0 millisecond, and repetition rate 1 PPS. The audio-
metry was also similar. Pre-exposure thresholds were the mean
of at least two audiograms giving threshold as a continuous
function of frequency from 2000 to 10000 cps. Each audiogram
took 70 seconds to complete. Post-exposure audiograms were be-
gun 30 seconds and usually also 3 minutes after the last pulse.
Audiograms were also run 6, 12 and, in many cases, 24 minutes
post exposure if recovery was not complete and the schedule
allowed. 16 subjects were used. 14 of these are shown with
initials and asterisks in Table 1. Subject number 43 was not
available, but was replaced by a non-sensitive subject (E.S.)
to increase (hopefully) the variance in our sample. One other
subject (T.H.) was included because of his experience of audio-
metry in other experiments and because an initial exposure gave
signigicant TTS.

The experimental procedure consisted of repeated exposures for
each subject (one day between exposures) in a trial and error
approach to a criterion maximum threshold shift of between 30
and 40 db in the first audiogram after exposure. The usual
method was to guess at an exposure capable of minimal signifi-
cant TTS (i.e. the ATT for number of pulses) using, in all but

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two instances,* a peak to peak pulse level of 168 db. If the
criterion TTS was reached quickly, the number of pulses was
dropped in the ratio of 3/4, 1/2 and 1/4 that number; other-
wise the procedure was to increase the number of pulses during
subsequent exposures.

Results

The foregoing experimental procedure resulted in measures of
temporary threshold shift at 13 frequencies 30 to 95 seconds
after exposure, 180 to 245 seconds after, etc. depending on the
frequency measured and the post-exposure audiogram. In order
to compare our data with those reported by other investigators
it was decided to use recovery curves previously determined
from exposures to steady state noise to estimate the hearing
loss two minutes after exposure, from the first post-exposure
audiogram. The curves used for this are given in Fig. 3.

The extrapolated TTS_2 values were plotted for each subject as
a function of the number of pulses in the exposure. Separate
figures were prepared for test frequencies 2000 cps (see Fig. 4,
6, 8) and the means of TTS_2 at 2200-2500 cps, 3000-3500, 4000-
4500 (see Fig. 5, 7, 9), 5000-5500, 6000-7000, and 8000-9000 cps.

Data already given have shown that wide individual differences
exist in susceptibility to impulse noise. Preliminary examina-
tion of the present data indicates that this is true even for the
selected group of 16 subjects used in the present study.

---

*One subject (B.K.) objected to peak to peak levels above 162 db
on the grounds that they hurt. The other (W.B.) proved highly
susceptible to the pulses. Pulse level was, therefore, dropped
in W.B.'s case to 156 db peak to peak and the experiment con-
tinued as with the other subjects.

For this reason the results from the 16 experimental subjects
were divided into three groups. Results for the six most sensi-
tive subjects are plotted in Figs. 4 and 5, the three next most
sensitive in Figs. 6 and 7 and for the seven least sensitive in
Figs. 8 and 9.

Clear association between number of pulses and TTS_2 at any fre-
quency is present in only the first two of these groups, total-
ling nine subjects. Data from the remaining seven subjects
(Figs. 8 and 9) are not included in the figures following Fig. 9
because they show no significant hearing loss.

The considerable degree of variation still present within each
group suggested the further classification of the two most sen-
sitive groups into four sub-groups. The most sensitive sub-
group now comprised subjects W.B., C.G.; the second most sensi-
tive, subjects S.C., W.H., D.M. and W.R.; The third, subject
H.P.; and the fourth most sensitive sub-group, subjects J.H.,
B.K. Mean TTS_2 at each of the test frequencies were plotted
for each of these four sub-groups as a function of the number
of pulses. Examples of the test frequencies of 2000 and mean
of average and 4000 and 4500 cps are presented in Figs. 10 and
11. The smoothed curves fitted visually to these data are re-
drawn in Figs. 12-15 for each frequency and each sub-group. The
curves are superimposed in Fig. 15 and average curves over all
test frequencies drawn for each sub-group of subjects in Fig. 16.

Discussion

In setting up the experimental procedure and initial plot of the
data of Experiment III three assumptions were made. First it
was assumed that a series of impulse-type noises acts cumulatively
in producing temporary threshold shift, i.e. that hearing loss

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can result from a series of otherwise harmless impulsive noises
if they occur close enough together in time. Second, it was
assumed that individual differences in the amount of TTS_2 fol-
lowing a series of acoustic pulses were due to differences in
the number of pulses necessary to produce initial threshold
shift. The number of pulses thought to be necessary to produce
temporary threshold shift persisting for two minutes after ex-
posure was called "acoustic trauma threshold (ATT) for number of
pulses." The third assumption was that the rate of increase of
TTS_2 as the number of pulses is increased is the same for all
ears once the critical number of pulses known as "ATT for number
of pulses" was reached.

The fact that all of the smoothed curves of Figs. 12-16 are
exponential in form suggested that a family of curves of the
same general form could take account of the diversity of the
data and still provide a general account of the relation between
TTS_2 and number of pulses.

Our assumption that the function relating number of pulses and
TTS_2 is the same form for all individuals can be maintained
while still keeping a good fit to the data by use of the set of
curves illustrated in Fig. 17.

The plausibility of this as a general hypothesis of the relation
between number of pulses and TTS_2 was aided somewhat by the fact
that in extrapolating the uppermost curve the line can be made
to merge quite easily with the 50 db level, commonly taken as
the point beyond which the likelihood of permanent damage is
increased. At this level also the rate of recovery of TTS_2
is reduced.[4]   While the reasons for these phenomena are
obscure, their occurrence after "TTS_2" of 50 db or more suggests

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that this is the "threshold" of permanent damage, which may have
a different mechanism to TTS, and produce a curve of different
shape to the rather complete appearing pattern of curves suggested
in Fig. 17.

Comparison of Figs. 15 and 16 shows the general similarity of
the curves with those in the hypothetical case of Fig. 17.
Such curves are generally known as Gompertz curves, the general
equation of which has the form

$$Y = Vg^{h^X}$$

i.e. the dependent variable is a double exponential function of
X, and V is a constant which gives the hypothetical or empirically
determined upper limit for Y. The equation generates both the
negatively accelerating function shown by our most sensitive
subjects and an initially positively accelerating function, de-
pending upon whether or not the constant g is more or less than
$\frac{1}{e}$. In both cases g and h must be fractional and positive to
give the initially positively accelerated and then negatively
accelerated functions suggested in Fig. 17. In the present
context Y and X are the variables TTS_2 and number of pulses re-
spectively, V is the empirically determined (or guessed) 50 db
upper limit of TTS_2, g is the Y intercept, or amount of TTS_2
after a single pulse and h is the rate of growth of TTS_2 with
number of pulses.

Tests of this hypothetical relation are given in Figs. 18 and 19.
The data points of Fig. 18 are the average TTS_2 over all test
frequencies (2000-9000 cps) for designated groups of subjects
as a function of number of pulses. Fig. 19 gives the same in-
formation for average TTS_2 at 4000 and 4500 cps. X_1 is the
point of inflection of the smoothed curves, i.e. that value of

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X at which the curve changes from a positively to a negatively accelerated slope. It is noteworthy that this occurs in all cases at about 17.5 db TTS_2.

For three out of the four sub-groups (seven of the nine subjects) the second exponent h is very close to the same value (.982). The same exponent for the fourth sub-group averages .950. The relatively small degree of variation in this exponent, which represents the rate of growth of TTS_2 with number of pulses, is regarded as justifying the original assumption that the rate of growth of TTS_2 with number of pulses was the same for all ears regardless of their "acoustic trauma threshold."

Since the smallest number of pulses to which the ear can be exposed is one, the constant "g," or the point of origin of the growth function, is the proportion of 50 db TTS_2 produced by a single pulse. It is interpreted roughly as the extent to which the subject's ATT's have been overreached by the peak to peak' SPL's of the particular pulse used in this experiment. In this sense it is a measure of individual differences in suscepti-bility.

Most of the difference between the smoothed curves of Figs. 18 and 19 can be attributed to variation in this constant, supporting the third assumption that the source of individual differences is in the point at which TTS_2 first appears rather than the rate at which it grows after the subject's "acoustic trauma threshold" is reached. It is important to note, however, that the equation $Y = Vg^{h^X}$ implies that if "g" equals zero (there being no loss after a single pulse) TTS_2 will continue to equal zero no matter how many pulses are presented. This implication is confirmed empirically in our data by the failure of seven of our sixteen

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subjects to show significant TTS_2 after as many as 200 success-
ive pulses. Our second assumption that individual differences
consist in part of the number of pulses necessary to produce
initial threshold shift should therefore be dropped in favor of
specifying the ATT in terms of parameters of the single pulse
necessary to produce an infinitely small but significant TTS_2
and hence "g." In practice this will, of course, involve ex-
posing some subjects to more than one pulse, unless the methods
of detecting TTS_2 are improved.

The usefulness of these values of "g" as a measure of individual
susceptibility to this type of pulse is limited, since the par-
ticular values derived in this experiment obviously apply only to
this repetition rate and peak to peak levels. In order to derive
a scale of susceptibility to this type of pulse which would be
applicable to all people it would be necessary to know the low-
est level at which a pulse of the type we are using was capable
of producing some TTS_2, no matter how small, in the least sus-
ceptible ears. The same exposure could conceivably produce the
maximum (50 db) TTS_2 in some ears, whose "g" would then equal
one. Presumably there would be a distribution of TTS_2 between
these limits, and hence a distribution of "g" to be entered in
the equation $TTS_2 = 50(g)^{.982^x}$. If, for example, S showed a
TTS_2 of 8 db following exposure to one pulse at this level, then
it could be calculated that his TTS_2 after 80 such pulses would be

$$TTS_2 = 50(.16)^{.982^{80}}$$

$$= 50(.16)^{.2333}$$

$$= 32.6 \text{ db.}$$

Such a calculation procedure would still be limited to triangular acoustical waveforms with a rise time of 0.5 millisecond, duration 1.0 millisecond, and a repetition rate of 1 PPS. It would also apply to only one peak to peak pulse level.

However, arriving at the corrections to be applied for alterations in peak to peak level of the pulse, rise time, and duration should be relatively straightforward, and work is progressing under U. S. Army sponsorship at our laboratory and elsewhere on these questions. Further confirmation of the 50 db "guessed" "safe" upper limit for TTS_2 is also required. Although we feel that the hypothesis developed above for growth of TTS as a function of the number of exposures may have promise as a general description of the growth of TTS from acoustic impulses, it is put forth here as but one possibility worthy of discussion.

In an exploratory study on TTS from impulses, Ward et al[4] concluded that the growth of TTS for most frequencies is linear with time, or number of pulses when given at a constant rate. We are not at all sure that the fitting of straight lines to our data to indicate a linear growth in TTS as a function of number of pulses would not ultimately prove to be the best procedure. The necessity of averaging data such as ours across a limited number of subjects can easily result in misleading, though suggestively interesting, curvatures.

EXPERIMENT IV

This experiment was designed to explore the effect of peak to peak pulse level upon TTS_2. The audiometric test procedure was the same as that used in the previous study. The subjects were the nine most sensitive subjects (W.B., C.G., S.C., W.H., D.M., W.R., H.P., J.H. and B.K.) of Experiment III.

For this study we exposed the subjects to impulses at peak to peak sound pressure levels of 156 and 162 db. Comparable data for a level of 168 db was available from the results of Experiment III. All other variables, including the number of pulses and the repetition rate, were held constant.

Results

Examples of the results of this procedure are given in Figs. 20 and 21. The hearing losses, from first audiogram begun 30 seconds after exposure, were corrected to 2 minutes post exposure by using the recovery curves of Fig. 3.

While the data for each subject and test frequency shows many inconsistencies, the mean TTS_2 over all subjects and test frequencies, as shown in Fig. 22, appears to be linear, and to increase 3 db with each 6 db increase in peak to peak level.

EXPERIMENT V

The final experiment in this series was undertaken because of the
wide differences observed between subjects in amount of TTS_2 fol-
lowing comparable exposures to triangular pulses, differences
which appeared to be greater than those commonly found following
exposure to steady state pure tones or octave band noise. Because
our subjects were selected on the basis of susceptibility to im-
pulse type noise,* this experiment was aimed at finding out the
degree of correlation between susceptibility to impulse noise and
octave band noise rather than at estimating the size of the vari-
ance in TTS_2 due to the two types of noise in the population at
large.

The sixteen subjects used for Experiment III were exposed to
10 minutes of pre recorded octave band noise in the frequency
range 1200-2400 cps. The noise was obtained from a GR noise
generator and altered to a cutoff characteristic of 36 db per
octave. The overall sound pressure level of the exposure in all
cases was 110 db, as measured in the ear canal on an artificial
head.

Audiometric procedure was the same as in Experiments III and IV.
The first audiogram after exposure began 30 seconds post.

Results

Hearing losses, TTS_2, at 2000 and 4000 cps are given in Table 2.
Also given in Table 2 are: (a) the estimated average TTS_2 at
2000 and 4000 cps following exposure to 60 impulses at a level
of 168 db (these estimates are derived from the data in Figs 4-9),

*However, because of the small degree of TTS observed in most
persons in our selection test (see Table 1), we are not certain
that our "moderately" sensitive subjects do not really represent
the average of the general population.

(b) the rank orders of the average TTS_2 for the two noises, and
(c) the rank order correlations for the average of the TTS values
for 2000 and 4000 cps and for other test frequencies.

These coefficients indicate no significant positive correlation
in these 16 subjects between susceptibility to the impulse type
noise and hearing losses due to noise in the octave band 1200-
2400 cps. Although the pattern of increasingly higher negative
correlations with test frequencies is perhaps interesting, the
highest correlation at test frequencies 8000-9000 cps is nega-
tive and accounts for only 25% of the variance.

The results of this experiment show a striking difference be-
tween the ranges of individual differences in susceptibility to
impulse and steady state noise. This is shown in Fig. 23 where
we see that a difference of about 20 db separated the largest
and smallest TTS following exposure to steady state noise in
contrast to a range of about 55 db for impulse noise. It is
interesting to note that the range between the least and most
sensitive ear is about the same for the pre-exposure thresholds
(see Fig. 2) as it is following exposure to steady state noise.

The most obvious, but as yet unproven, explanation for this
greater variability is, of course, that the auditory reflex
relaxes at different rates for different subjects or conversely,
is not as readily elicited in some persons as in others. Al-
though it is believed that the muscles involved in the auditory
reflex relax in the typical ear in a matter of a few hundred
milliseconds, our data suggest that in the "tougher" ears per-
haps the muscles are at least partly constricted after as long
as one second, thereby affording some protection from succeeding
impulses given at the rate of 1 per second; whereas in our

"tender eared" subjects the muscles are completely relaxed in
one second. It is also possible, of course, that our "tender
eared" subjects completely lack this reflex. We are planning
additional studies on this point.

Reliability of Audiograms

During the course of the experiments just reported we accum-
ulated a number of "pre-exposure" audiograms (the audiogram
given prior to exposure to noise) for 18 of our subjects.
Hopefully, these audiograms should, for each subject, be quite
similar; if so, the rather small threshold shifts noted as the
result of exposure to impulse and steady state noise could be
taken as significant.

The general reliability of the audiograms obtained from our
subjects is given in Fig. 24. The mean difference between the
first pre-exposure audiogram and succeeding pre-exposure audio-
grams (given at least 1 day apart) is -1.2 db, indicating per-
haps some slight improvement by these subjects in ability to find
their thresholds with continued use of the audiometer. The stand-
ard deviation of 1.4 db demonstrates, however, that even with a
large amount of audiometric testing (each subject had an average
of 10 pre-exposure audiograms) the audiograms are very consistent.

Actually, the effects of noise on hearing is taken as the differ-
ence between two audiograms taken in fairly close succession.
This testing procedure is approximated if we take the first two
pre-exposure audiograms for each subject and compare the differ-
ence between them. Doing this, we found mean differences of
+.5 db and -.7 db and standard deviations of 2.4 db and 2.4 db
at 2000 cps and 4000 cps respectively.

-17-

These test-retest reliability data indicate that consistent dif-
ferences between pre- and post-exposure audiograms of but 2-3 db
at several critical test frequencies will usually be found with
further experimentation to be statistically reliable differences
and presumably attributable to some interviewing factor, such as
exposure to intense noise.

REFERENCES

1. Carter, N. L., J. H. Ball and K. D. Kryter, "Studies of
    Temporary Threshold Shift Caused by High Intensity Acoustic
    Transients." Bolt Beranek and Newman Inc., Report No. 916,
    January 1962, Contract No. DA-49-007-MD-985.

2. Ball, J. H., "Instrumentation for a Study of Temporary
    Threshold Shifts Caused by High Intensity Acoustic Transients."
    Bolt Beranek and Newman Inc., Report No. 785, January 1961,
    Contract No. DA-49-007-MD-985.

3. Ward, W. D., W. Selters and A. Glorig, "Exploratory Studies
    of Temporary Threshold Shift from Impulses." J. Acoust. Soc. Amer.,
    33, 781 (1961).

4. Ward, W. D., "Recovery from High Values of Temporary Thresh-
    old Shift." J. Acoust. Soc. Amer, 32, No. 4, 497-500 (1960).

Table 1. Temporary Threshold Shift in 45 Subjects at 500, 2000, 4000 and 8000 cps Following Acoustic Pulses with Rise Time 0.5 millisecond, Duration 1.0 millisecond and a Repetition Rate of 1 Pulse Per Second (1 PPS).

S No.	Pulse Level in db Peak to Peak	40				80				120			
		2000	4000	8000	500	2000	4000	8000	500	2000	4000	8000	500
1	158 db	-3	-1	-7	-5								
2	" "	-1	7	1	5	-1	-5	4	7				
*3	" "	2	14	8	5								
*4(C.C.)	" "	6	13	-1	0								
5	" "	-5	4	1	3	-4	4	4	3				
*6(W.H.)	159 db	5	-2	24	4								
7	" "	2	-4	-1	5								
8	" "	-1	5	4	0	-3	-4	6	3	-3	-7	-1	1
9	" "	1	-1	2	-5								
10	" "	8	1	8	6								
11	" "	3	-1	9	-2	-7	-10	-12	3				
12	" "	-11	9	5	-4	-3	-3	-3	1				
13	" "	7	-1	3	8								
*14(B.K.)	" "	-2	3	11	-2								
*15(W.B.)	" "					37	12	16	4				
	" "	Begun 7'30" Post---				15	7	3	-1				
*16(B.P.)	" "	19	10	18	-8								
	" "	4	4	7	1	----Begun 6'00" Post							
17	" "	2	0	10	-4								
*18(J.C.)	" "	4	-5	20	-5								
	" "			12------		----Begun 5'00" Post							
*19(S.C.)	" "	2	8	11	6								
20	" "	-1	-1	0	-2	2	0	1	1				
21	" "	-2	-3	4	2								
22	" "	-7	2	-5	0	-8	3	9	5				
*23	" "	5	17	25	3								
24	" "					0	1	1	4				
25	" "					3	0	10	2				
26	" "					1	6	1	3				
*27(J.H.)	" "					14	2	6	2				
28	" "					4	0	2	9				
*29(C.G.)	" "					9	10	19	4				
30	165 db	1	0	-6	3								
31	" "	4	0	3	4								
32	" "	-3	5	7	6								
*33(D.M.)	" "					-1	-2	32	-1				
*34(A.McD)	" "					2	0	38	-1				
35	" "					4	3	-1	1				
36	" "					4	8	-5	4				
37	" "	Begun 3'30" Post---				(-5	1	-2	-2)	-1	-3	4	-3
	" "					(-1	-3	2	-3)				
38	" "					2	-2	-4	4	3	1	0	6
	" "	Begun 6'20" Post---				4	-1	1	-4				
39	" "					-1	0	0	5	4	2	5	11
*40(W.R.)	" "					6	10	22	4				
41(E.S.)	168 db	-1	5	4	3								
42	" "	1	1	-7	-7								
43	" "	12	1	4	0								
*44(H.P.)	" "					1	9	24	9				
*45(S.C.)	" "					10	5	1	1				

Table 2. Rank Order Correlation between TTS_2 from Acoustic Impulses and
Steady State Octave Band of Noise

TTS_2 from 1200-2400 cps Octave Band of Noise, 10 Min. Duration, SPL 110 db

S	2000	4000	Aver. 2000 + 4000	Diff. from Mean
WB	23	14	19	- 1
SC	20	22	21	+ 1
CC	23	40	32	+12
CG	14	15	14	- 6
JH	19	17	18	- 2
WH	21	16	18	- 2
BK	14	18	16	- 4
DM	28	13	23	+ 3
HP	19	17	18	- 2
WR	20	27	24	+ 4
ES	18	17	17	- 3
ST	16	17	16	- 4
TH	27	25	26	+ 6
JC	14	27	20	0
BP	11	8	9	-11

Mean=20 db

Estimated TTS_2 from 60 Pulses, 1 P/Sec, 168 db, (See Fig. 2)

Aver. of 2000 + 4000 cps	Diff. from Mean	TTS2 1200-2400 cps Band Noise Rank	TTS2 Impulse 60 P/Sec Rank	Diff. in Rank	D^2
55	+41	7	1	6	36
20	+ 6	5	4.5	0.5	.25
2	-12	1	12	11	121
50	+36	13	2	11	121
7	- 7	9	9	0	0
22	+ 8	9	3	6	36
9	- 5	11.5	7	4.5	20.25
10	- 4	4	6	2	4
8	- 6	9	8	1	2
20	+ 6	3	4.5	1.5	2.25
- 1	-15	10	14	4	16
- 1	-15	11.5	14	2.5	6.25
4	-10	2	10	8	64
- 1	-15	6	14	8	64
3	-11	14	11	3	9

Mean=14 db

ρ (Rank Order Correlations) at Specified Test Frequencies:

2000 + 4000 cps = +.1	4000 + 4500 = -.005	8000,9000 = -.51
2000 = +.24	5000 + 5500 = -.39	
2200 + 2500 = -.004	6000 + 7000 = -.33	

$$\rho = 1 - \frac{6\Sigma D^2}{N(N^2 - 1)}$$

a.

b.

c.
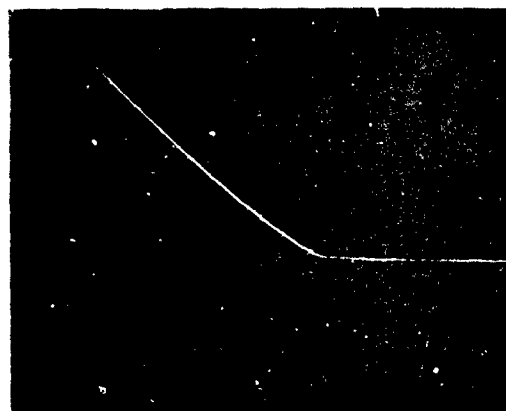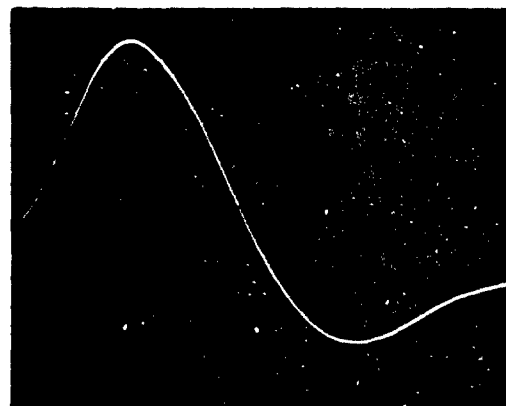
FIG.I   PHOTOGRAPH OF
a. PHOTOFORMER MASK
b. ELECTRICAL OUTPUT OF AMPLIFIER
c. ACOUSTICAL OUTPUT OF SPEAKER
AS SHOWN ON OSCILLOSCOPE

The horizontal (time) scale in b. and c. is 0.2 millisec per div.
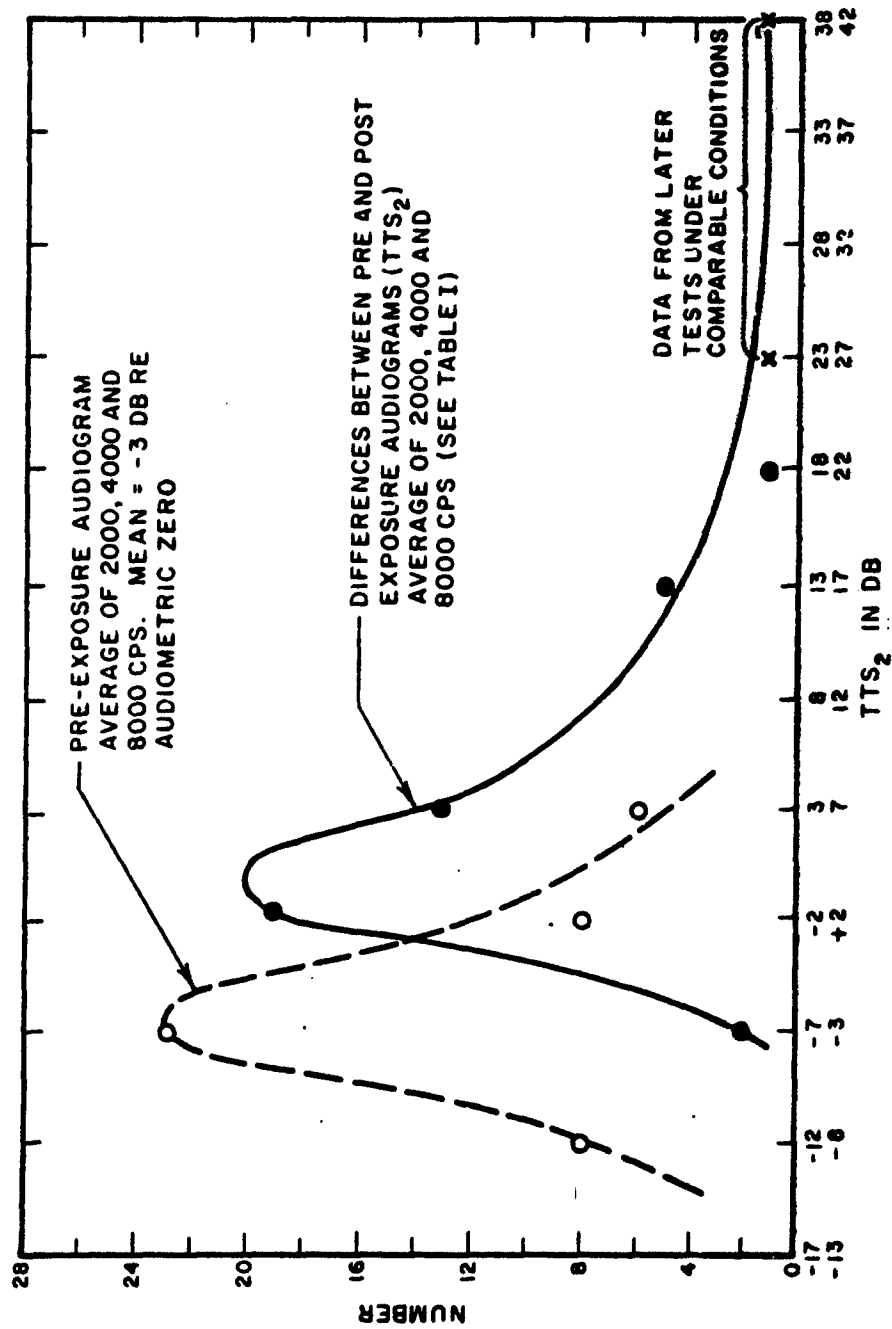
FIG. 2   PRE-EXPOSURE THRESHOLDS AND DIFFERENCE BETWEEN PRE AND POST EXPOSURE THRESHOLDS TO IMPULSES IN DB
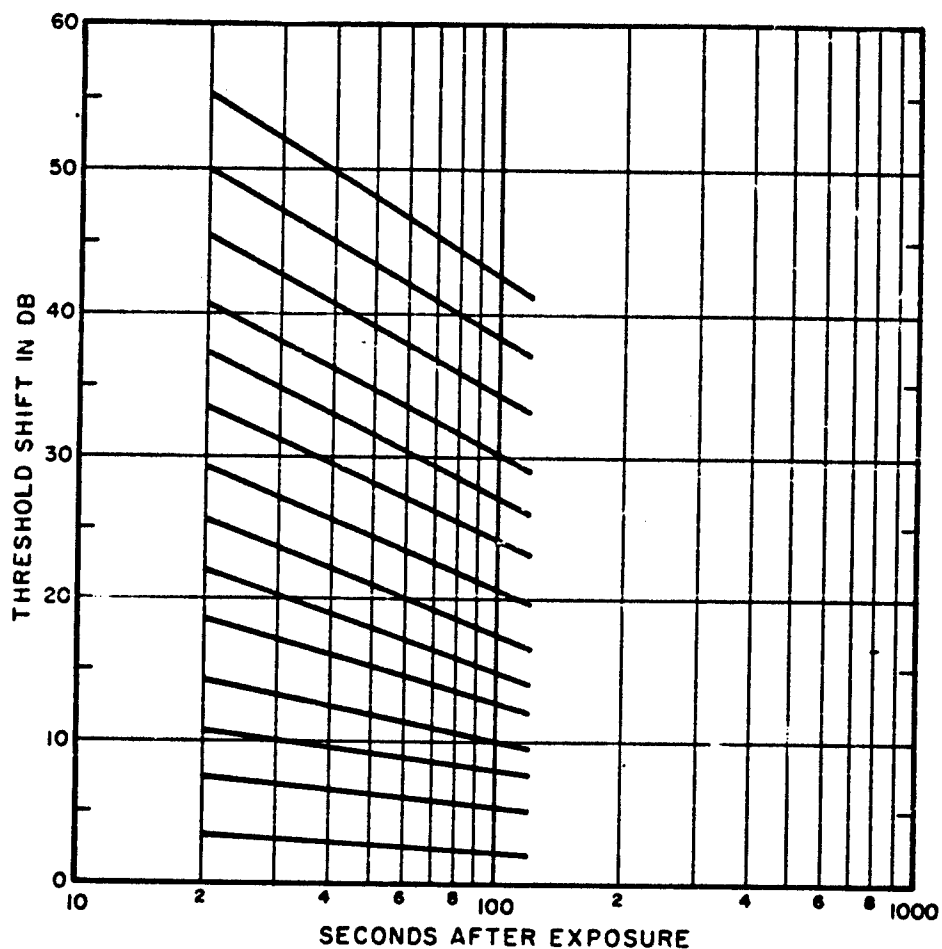
FIG. 3   RECOVERY CURVES USED IN ESTIMATING THE
AMOUNT OF HEARING LOSS TWO MINUTES
AFTER EXPOSURE (TTS$_2$) FROM MEASURE-
MENTS MADE 30 SECONDS ETC. AFTER
EXPOSURE
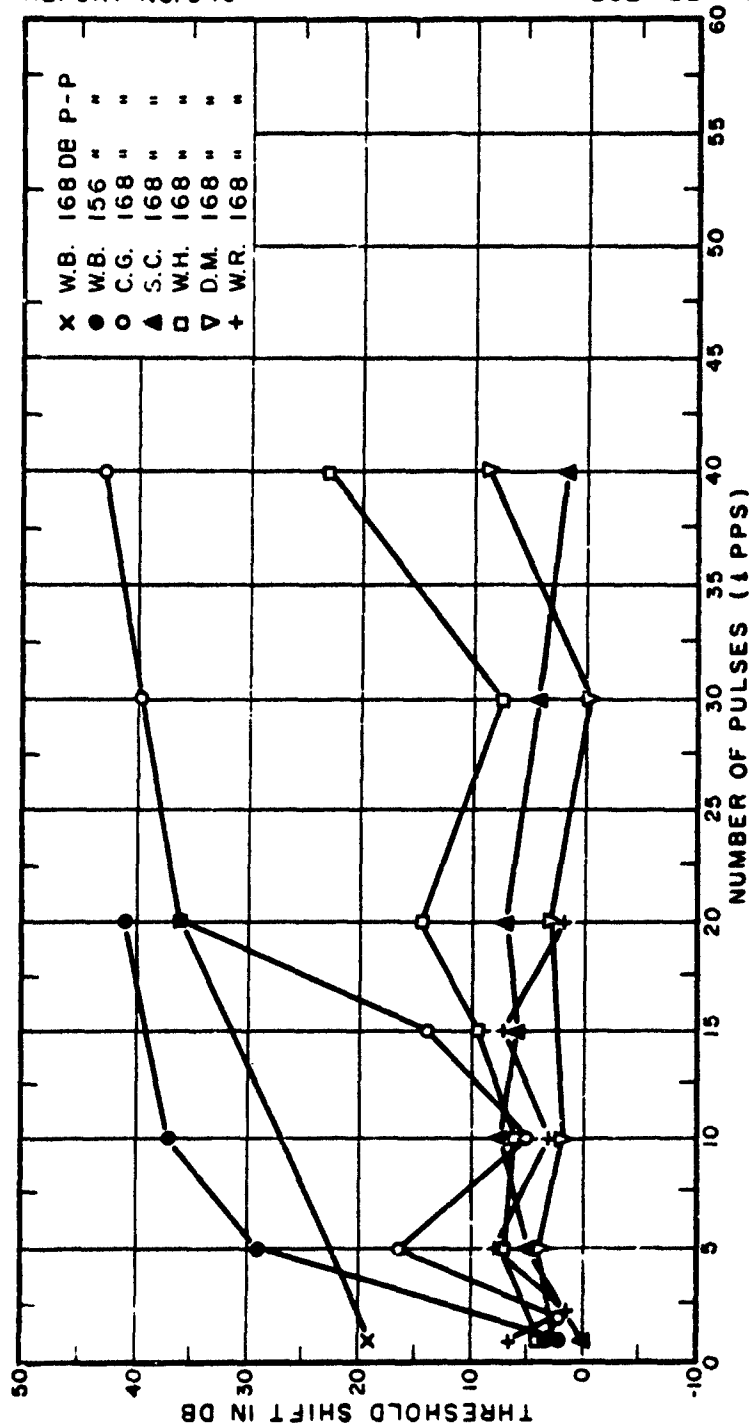
FIG. 4   TEMPORARY THRESHOLD SHIFT FOR THE SIX "MOST SUSCEPTIBLE" SUBJECTS AT 2000 CPS TWO MINUTES AFTER EXPOSURE. PARAMETER IS THE SUBJECT AND THE PEAK TO PEAK LEVEL OF PULSES IN DB
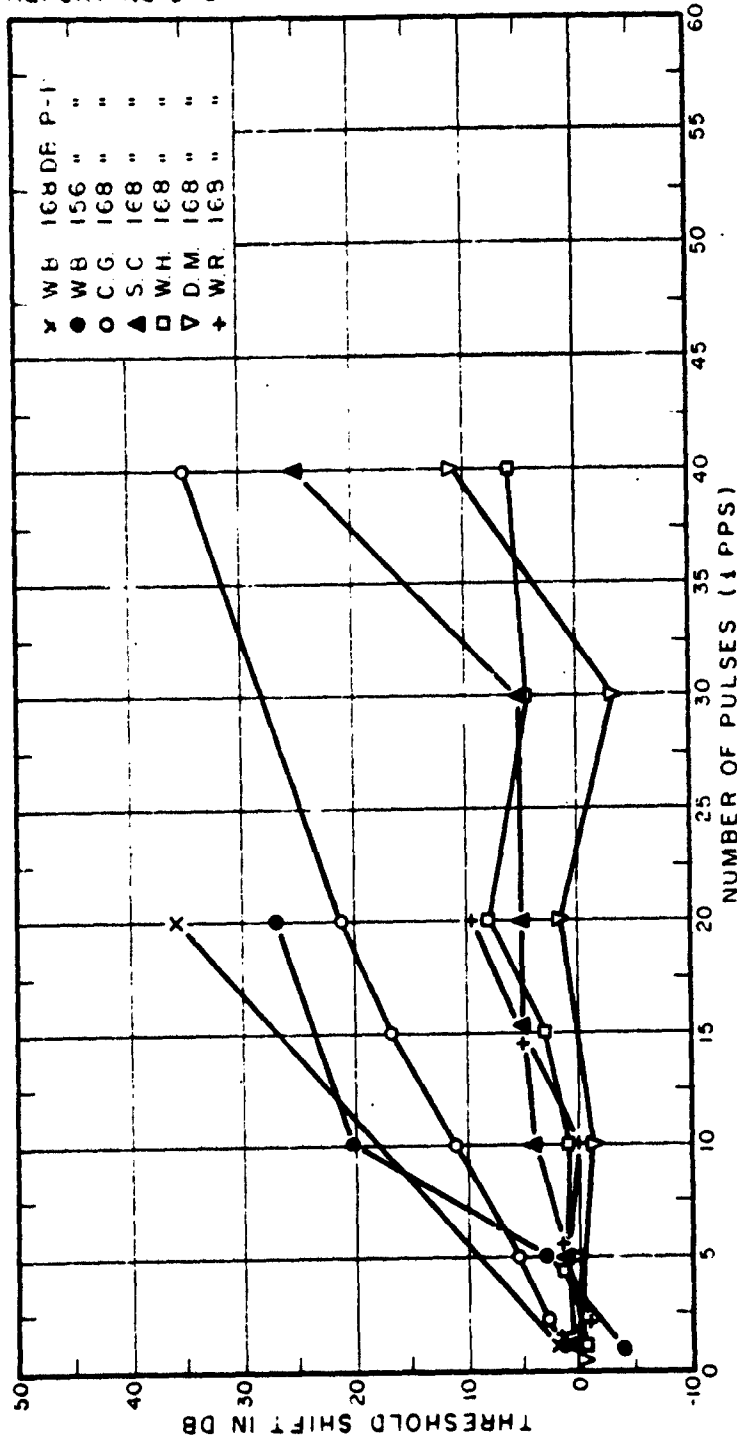
FIG.5   AVERAGE OF TEMPORARY THRESHOLD SHIFTS FOR THE SIX
"MOST SUSCEPTIBLE" SUBJECTS AT 4000 AND 4500 CPS TWO MINUTES
AFTER EXPOSURE. PARAMETER IS THE SUBJECT AND THE PEAK TO PEAK
LEVEL OF PULSES IN DB

THRESHOLD SHIFT IN DB

NUMBER OF PULSES (1 PPS)

● J.H. 168 DB P-P
○ B.K. 162 " "
□ H.P. 168 " "
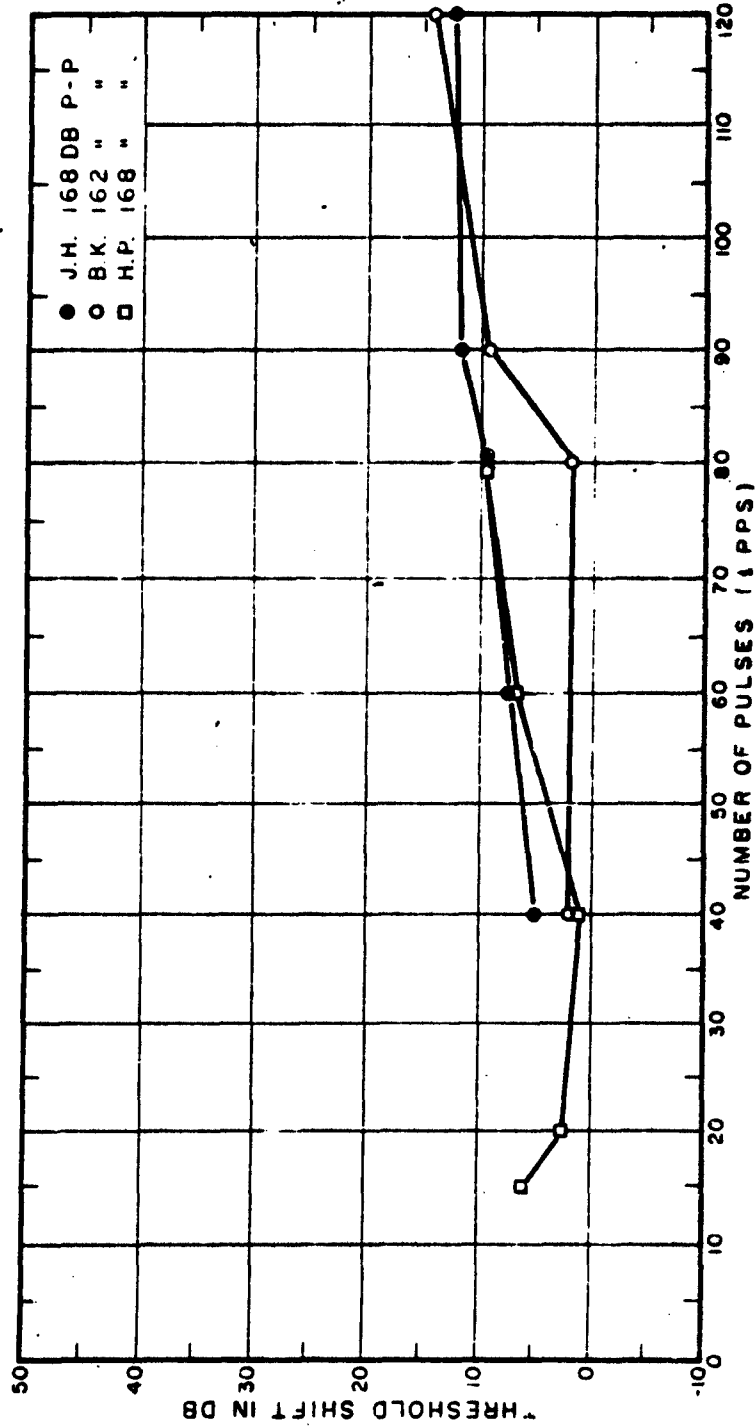
FIG. 6　TEMPORARY THRESHOLD SHIFT FOR THE THREE "NEXT MOST SUSCEPTIBLE" SUBJECTS AT 2000 CPS TWO MINUTES AFTER EXPOSURE. PARAMETER IS THE SUBJECT AND THE PEAK TO PEAK LEVEL OF PULSES IN DB
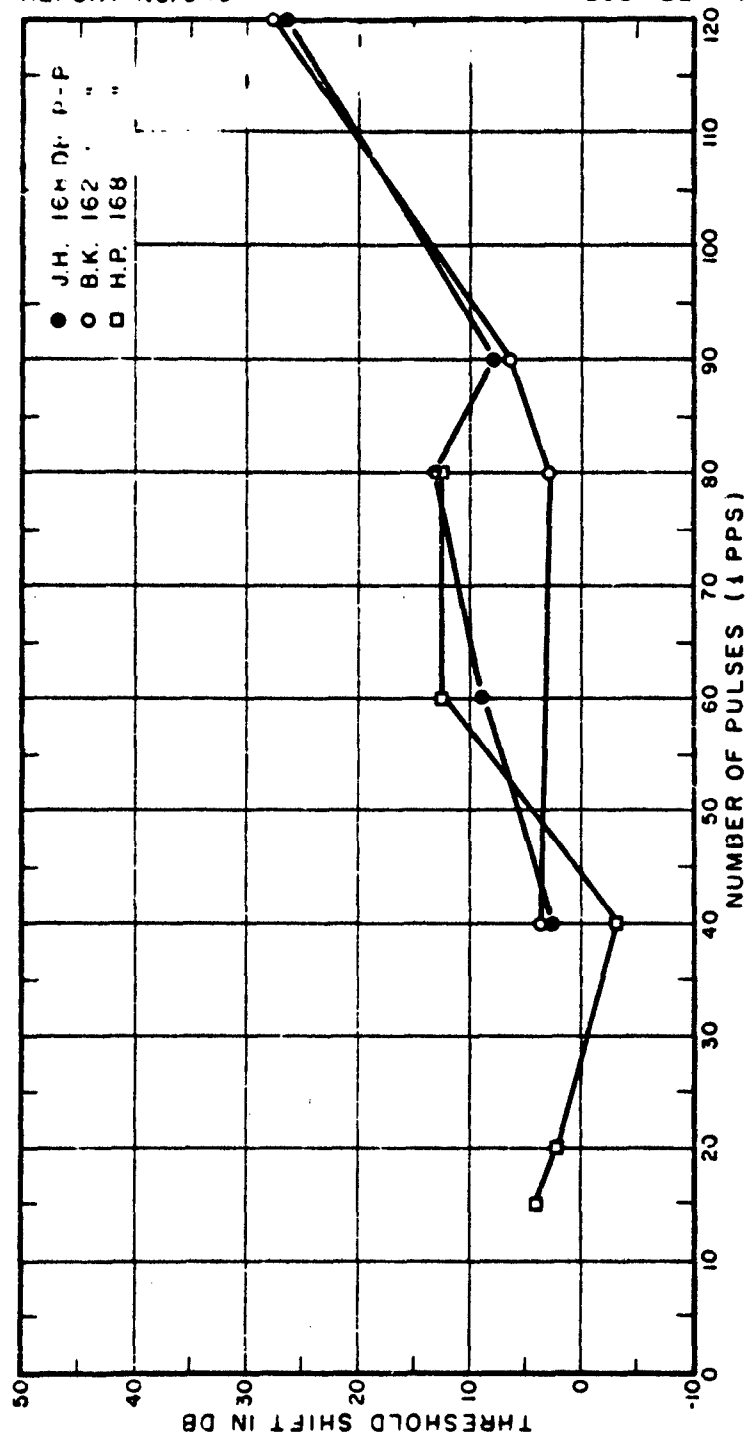
FIG.7   AVERAGE OF TEMPORARY THRESHOLD SHIFTS FOR THE THREE "NEXT MOST SUSCEPTIBLE" SUBJECTS AT 4000 AND 4500 CPS TWO MINUTES AFTER EXPOSURE. PARAMETER IS THE SUBJECT AND THE PEAK TO PEAK LEVEL OF PULSES IN DB
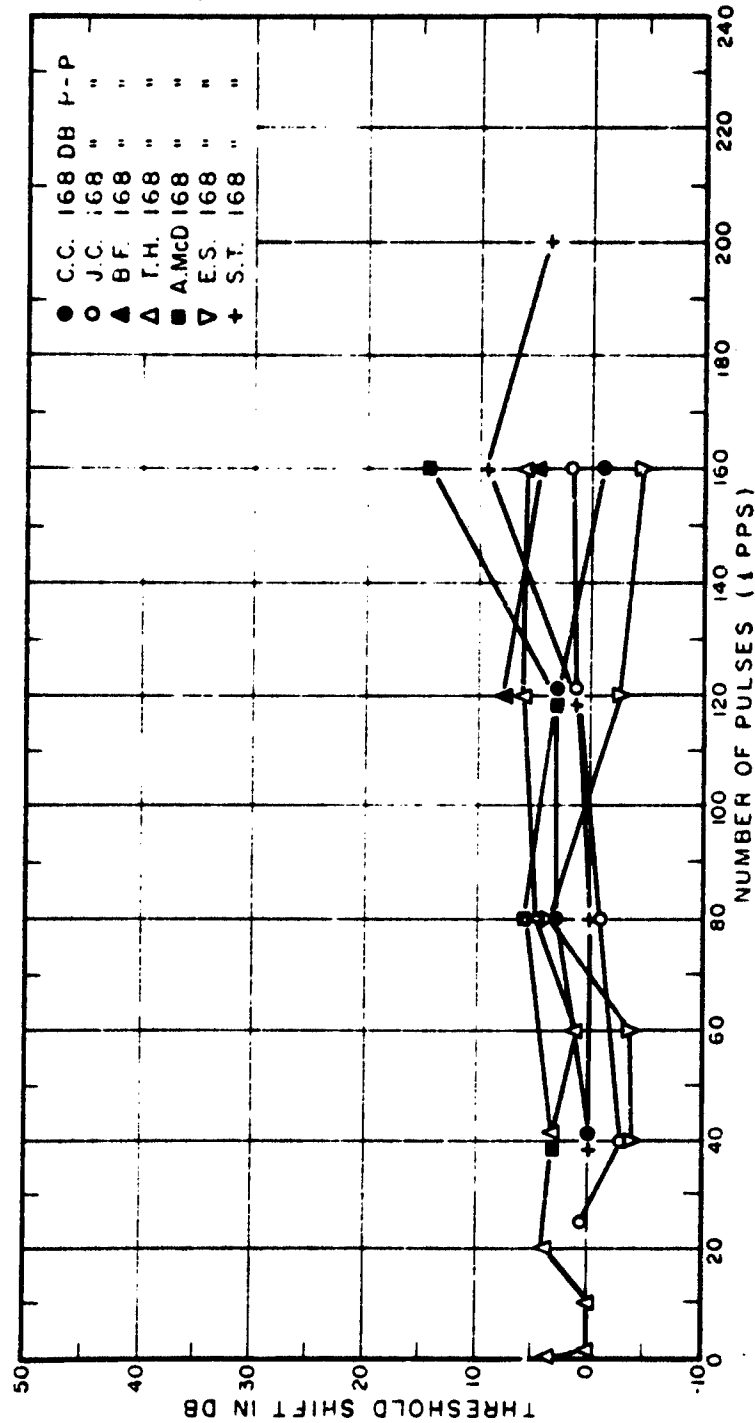
FIG. 8   TEMPORARY THRESHOLD SHIFT FOR THE SEVEN "LEAST SUSCEPTIBLE" SUBJECTS AT 2000 CPS TWO MINUTES AFTER EXPOSURE. PARAMETER IS THE SUBJECT AND THE PEAK TO PEAK LEVEL OF PULSES IN DB

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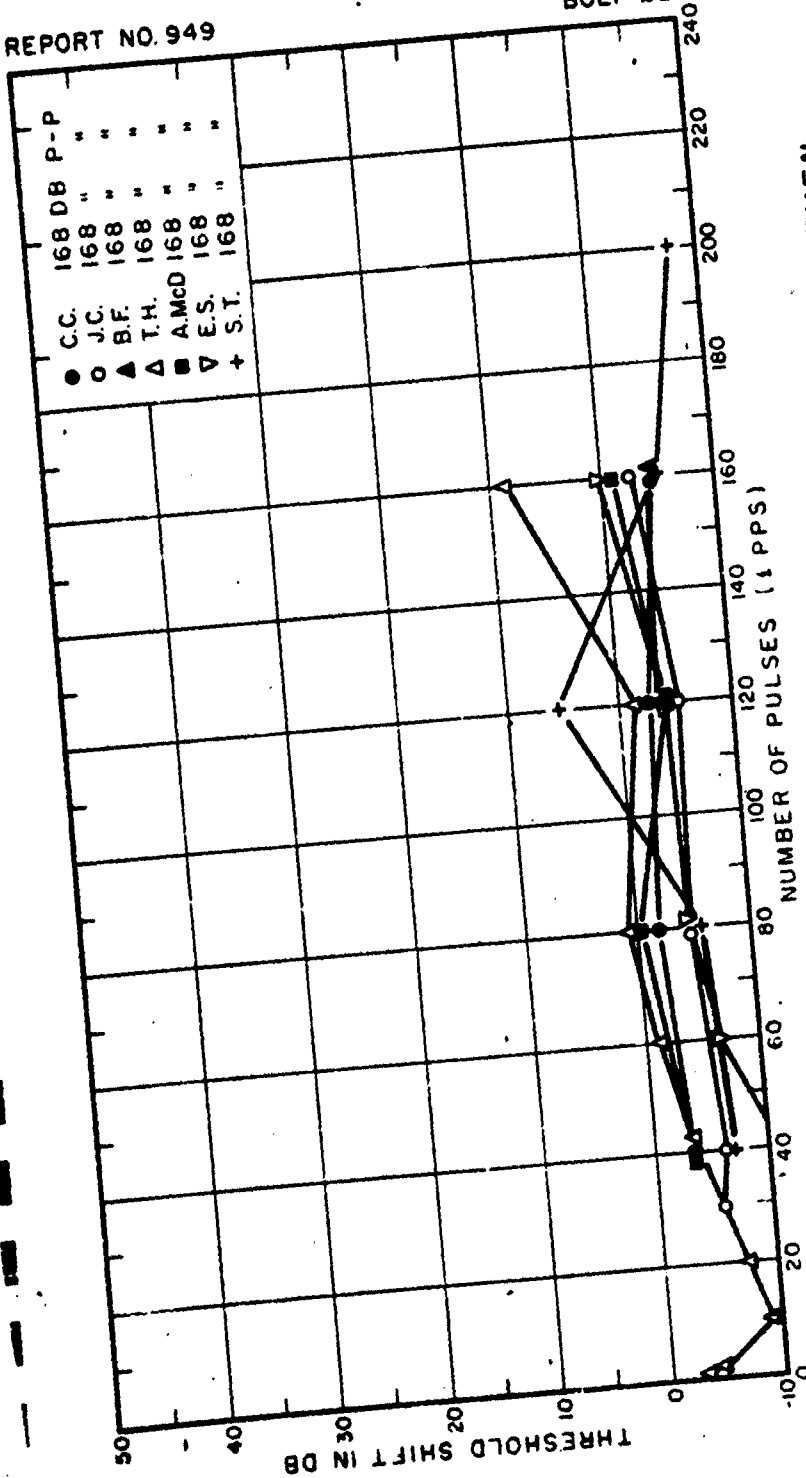
FIG. 9 . AVERAGE OF TEMPORARY THRESHOLD SHIFTS FOR THE SEVEN "LEAST SUSCEPTIBLE" SUBJECTS AT 4000 AND 4500 CPS TWO MINUTES AFTER EXPOSURE. PARAMETER IS THE SUBJECT AND THE PEAK TO PEAK LEVEL OF PULSES IN DB
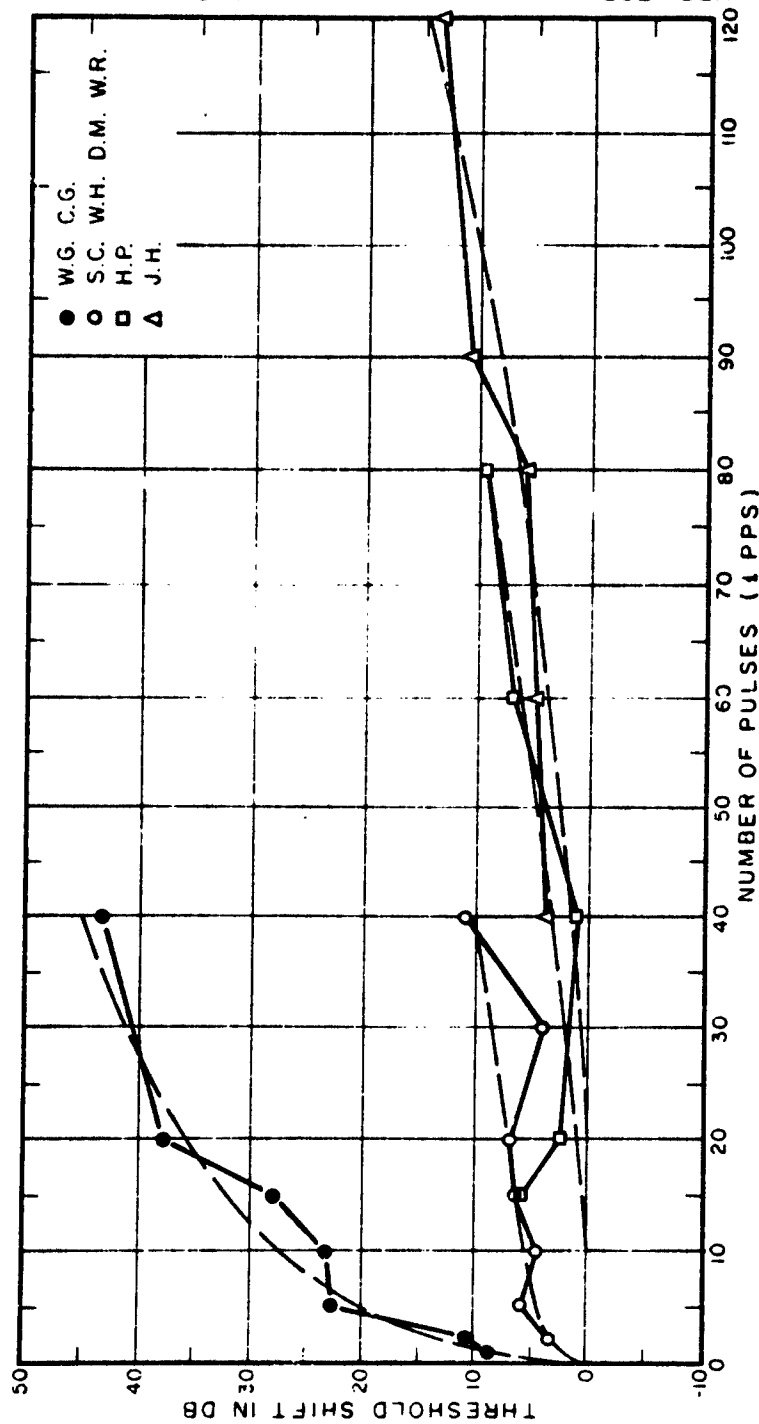
FIG.IO　MEAN THRESHOLD SHIFTS AT 2000 CPS TWO MINUTES AFTER EXPOSURE.
PARAMETER IS THE SUBGROUP OF SUBJECTS USED TO OBTAIN MEAN TTS$_2$
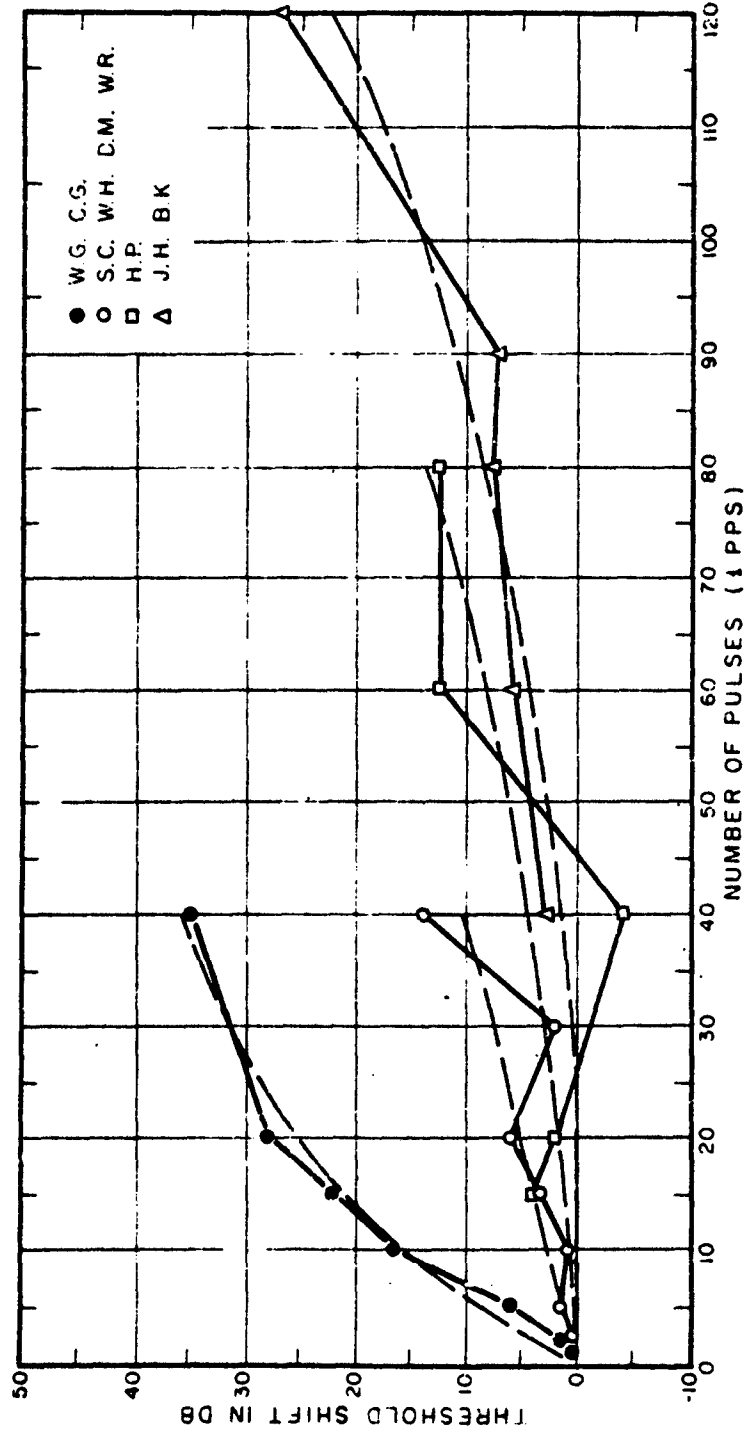
FIG. II   MEAN OF AVERAGE THRESHOLD SHIFTS AT 4000 AND 4500 CPS TWO MINUTES AFTER EXPOSURE. PARAMETER IS THE SUBGROUP OF SUBJECTS USED TO OBTAIN MEAN TTS_2

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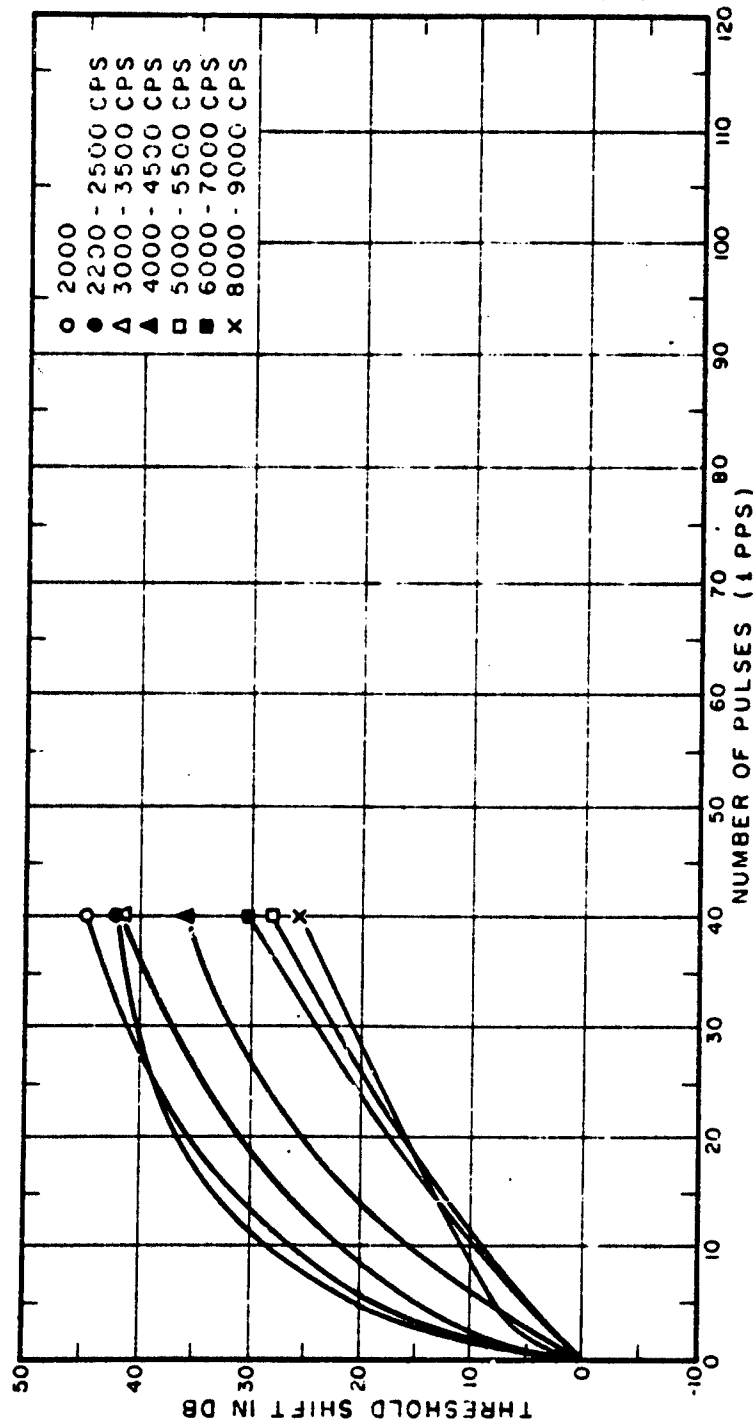
FIG.12 SMOOTHED AVERAGE TTS$_2$ OF SUBJECTS W.B. AND C.G. TWO MINUTES AFTER EXPOSURE AS A FUNCTION OF THE NUMBER OF PULSES. PARAMETER IS THE FREQUENCY OF TEST TONE.
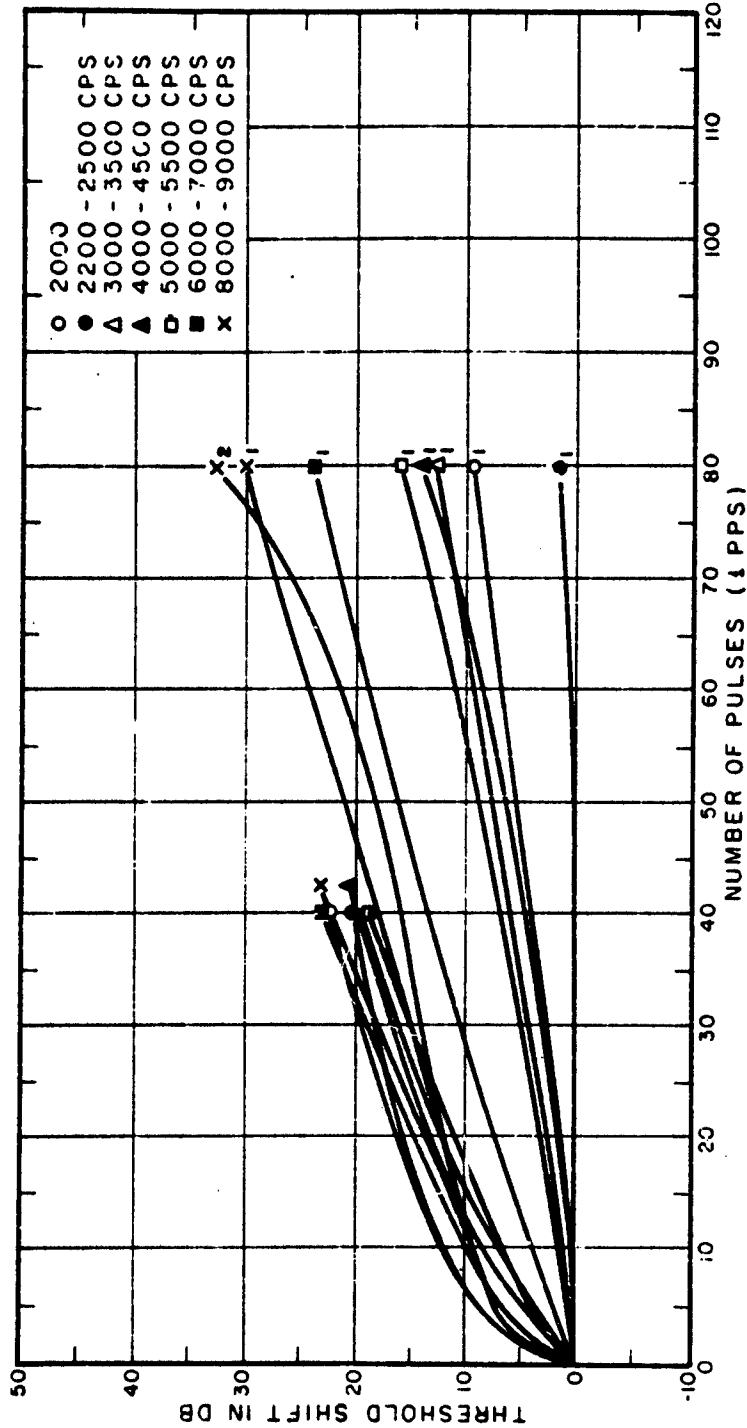
FIG.13   SMOOTHED AVERAGE TTS₂ OF SUBJECTS H.P. (WITH SUBSCRIPT) S.C. W.H. D.M. AND W.R. AS A FUNCTION OF THE NUMBER OF PULSES. PARAMETER IS THE FREQUENCY OF TEST TONE

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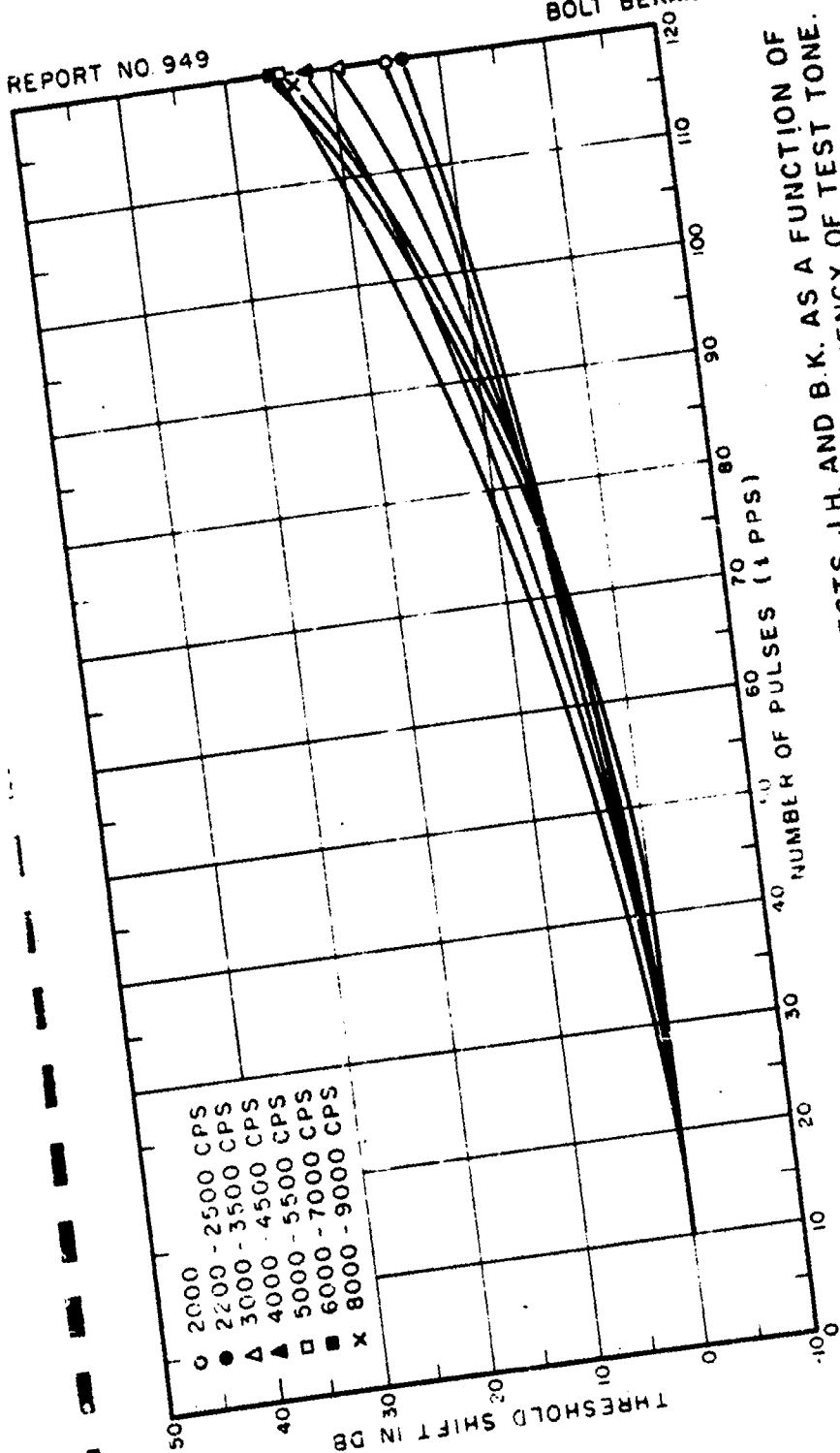
FIG. 14   SMOOTHED AVERAGE TTS₂ OF SUBJECTS J.H. AND B.K. AS A FUNCTION OF
THE NUMBER OF PULSES. PARAMETER IS THE FREQUENCY OF TEST TONE.
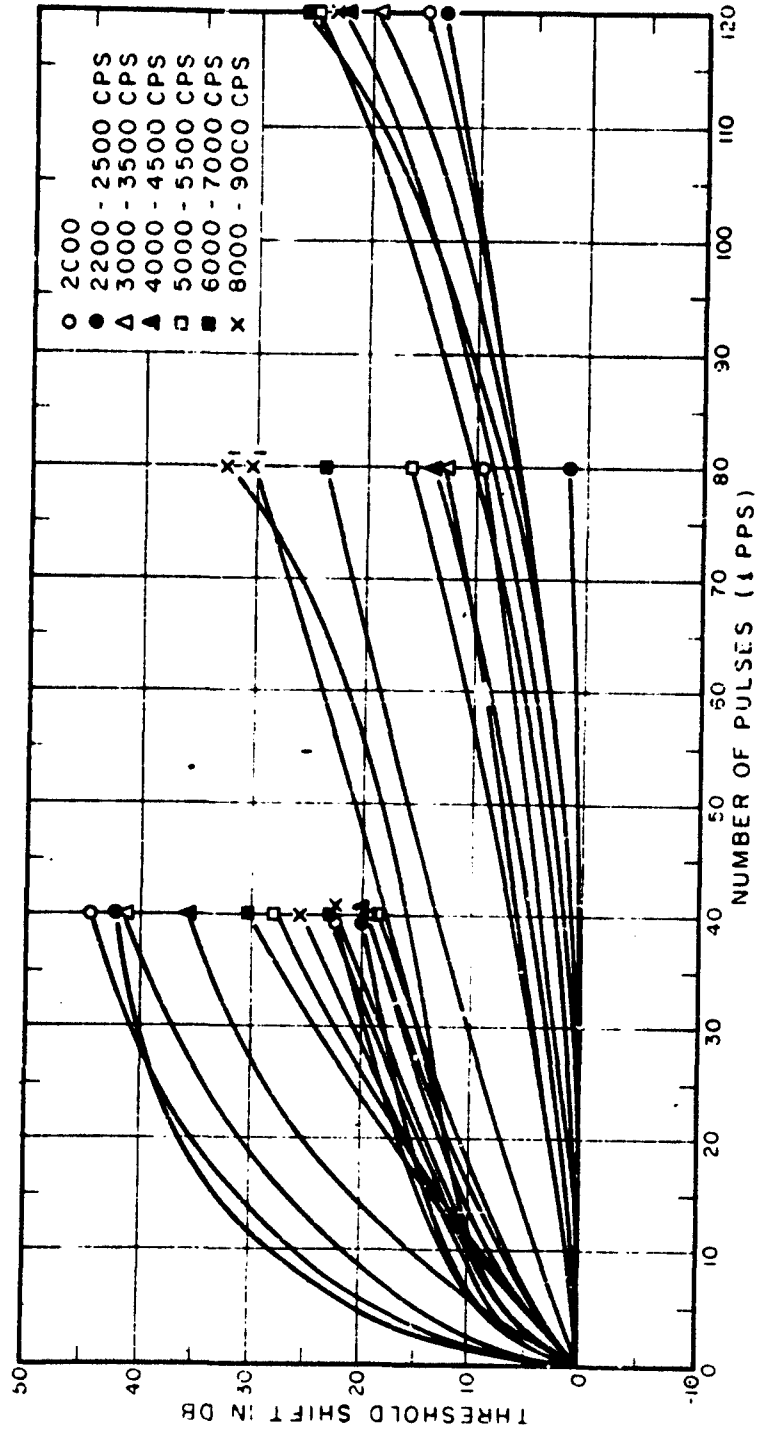
FIG. 15   SMOOTHED AVERAGE TTS$_2$ OF NINE SUBJECTS AS A FUNCTION OF THE NUMBER OF PULSES. PARAMETER IS THE FREQUENCY OF TEST TONE.
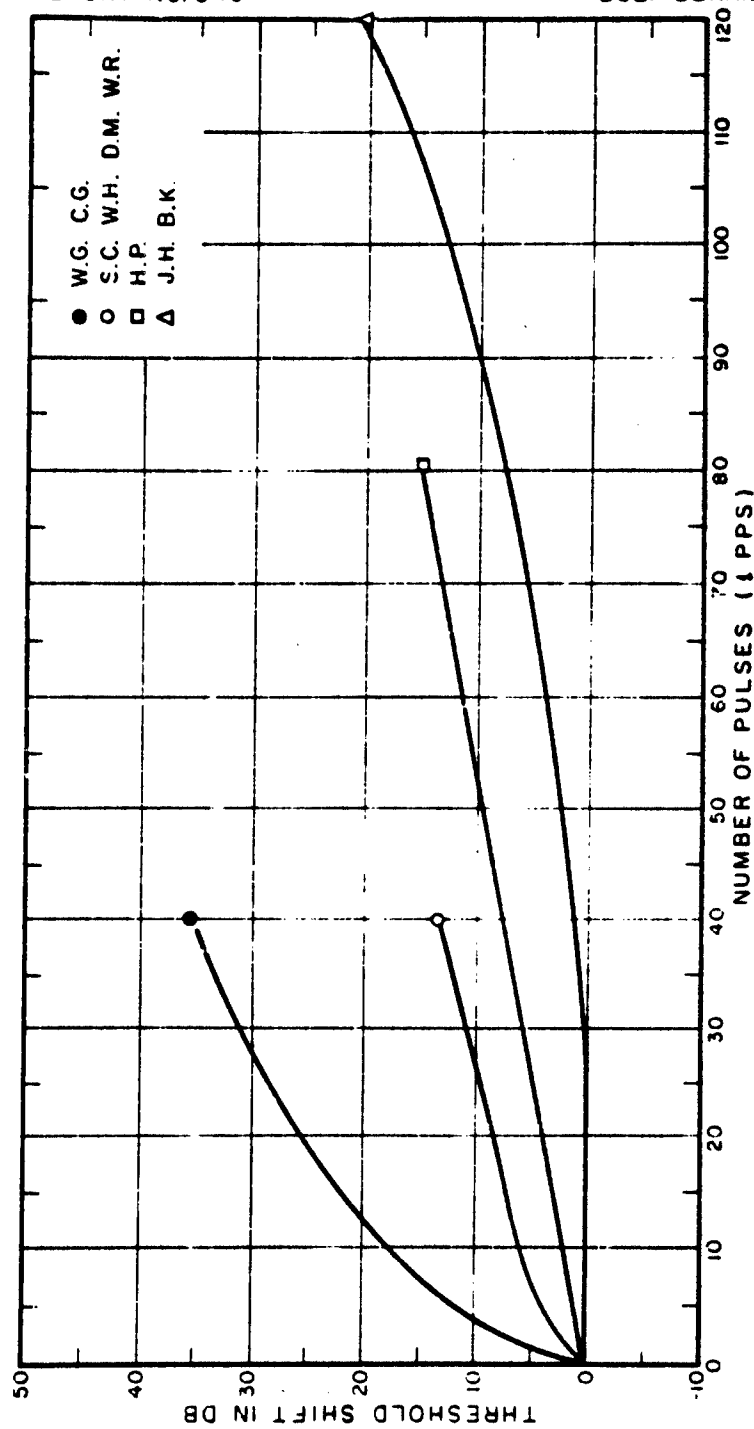
FIG.16   AVERAGE OF SMOOTHED CURVES OF FIG.15 OVER ALL TEST FREQUENCIES.
PARAMETER IS THE SUBGROUP OF SUBJECTS.
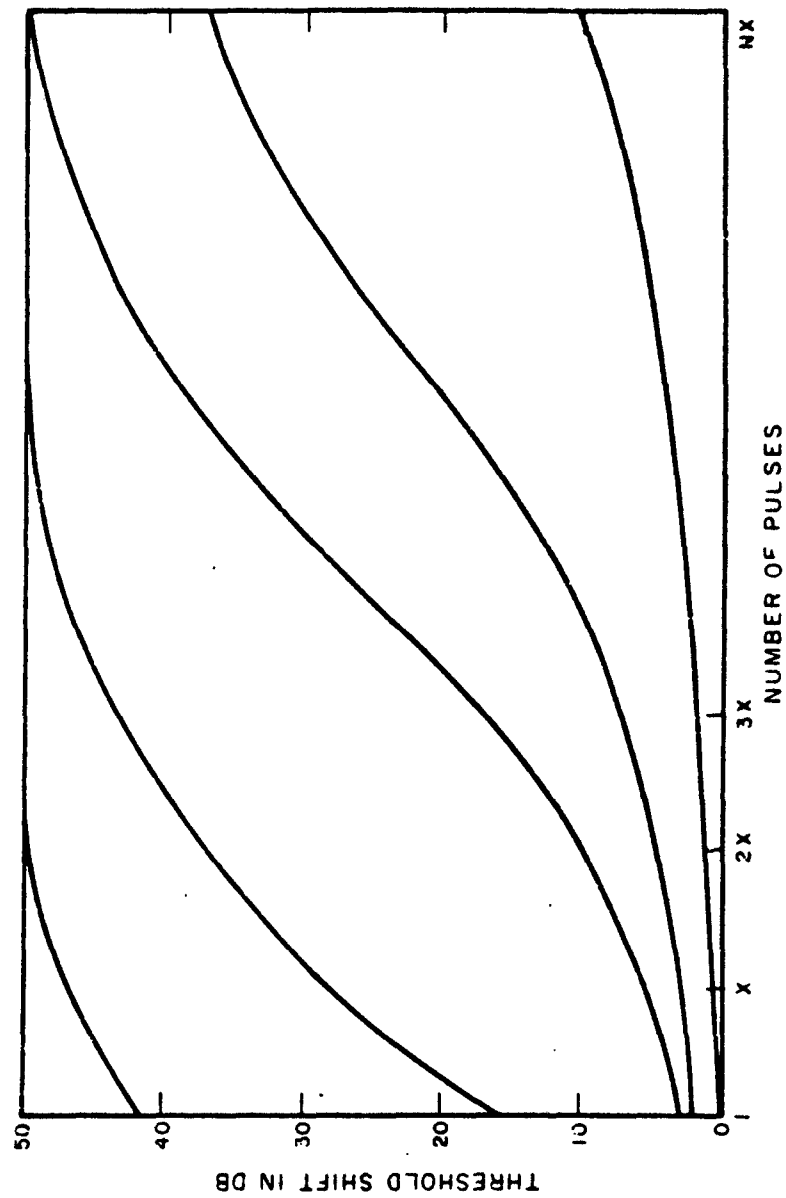
FIG. 17   HYPOTHETICAL RELATION BETWEEN NUMBER OF
         PULSES AND TTS$_2$
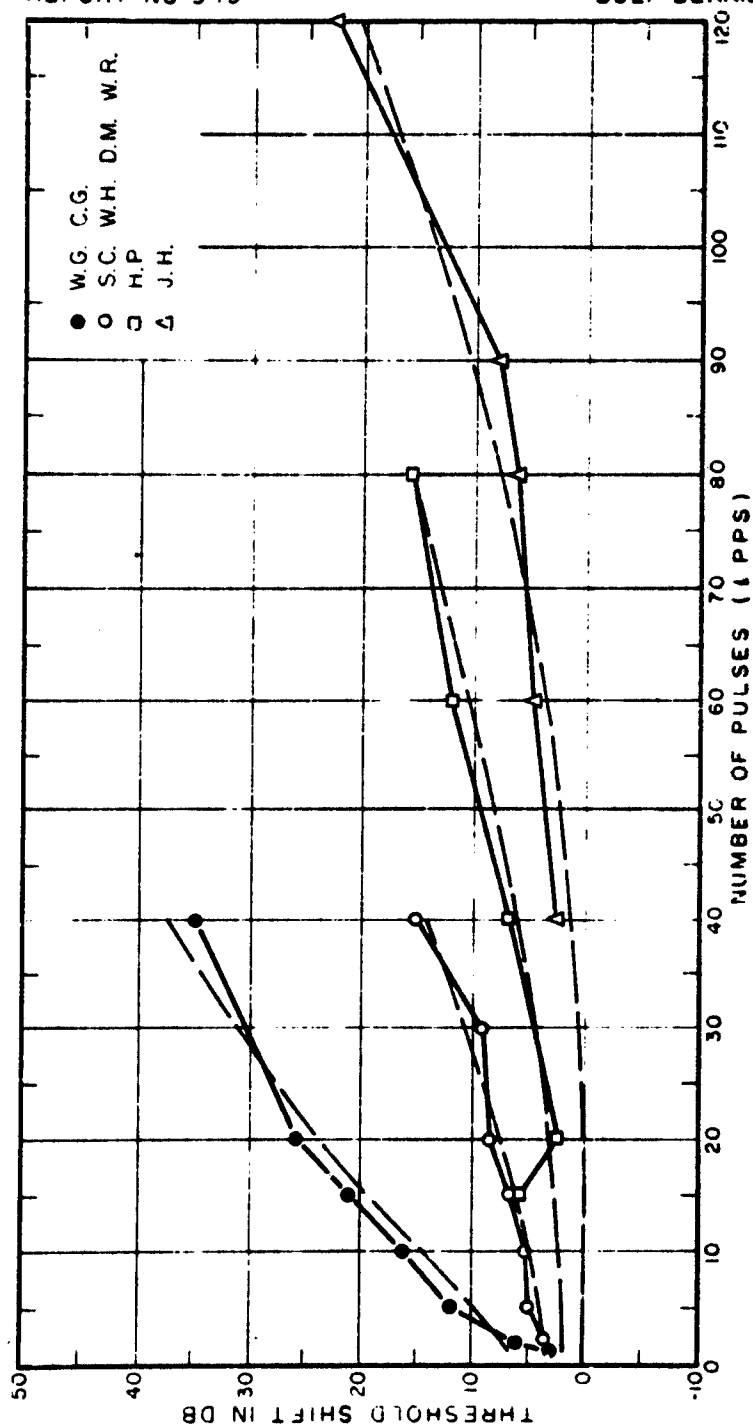
FIG. 18 AVERAGE TTS$_2$ OVER ALL TEST FREQUENCIES. SMOOTH CURVES ARE HYPOTHETICAL FUNCTIONS RELATING TTS$_2$ TO NUMBER OF PULSES. PARAMETER IS THE SUBGROUP OF SUBJECTS.
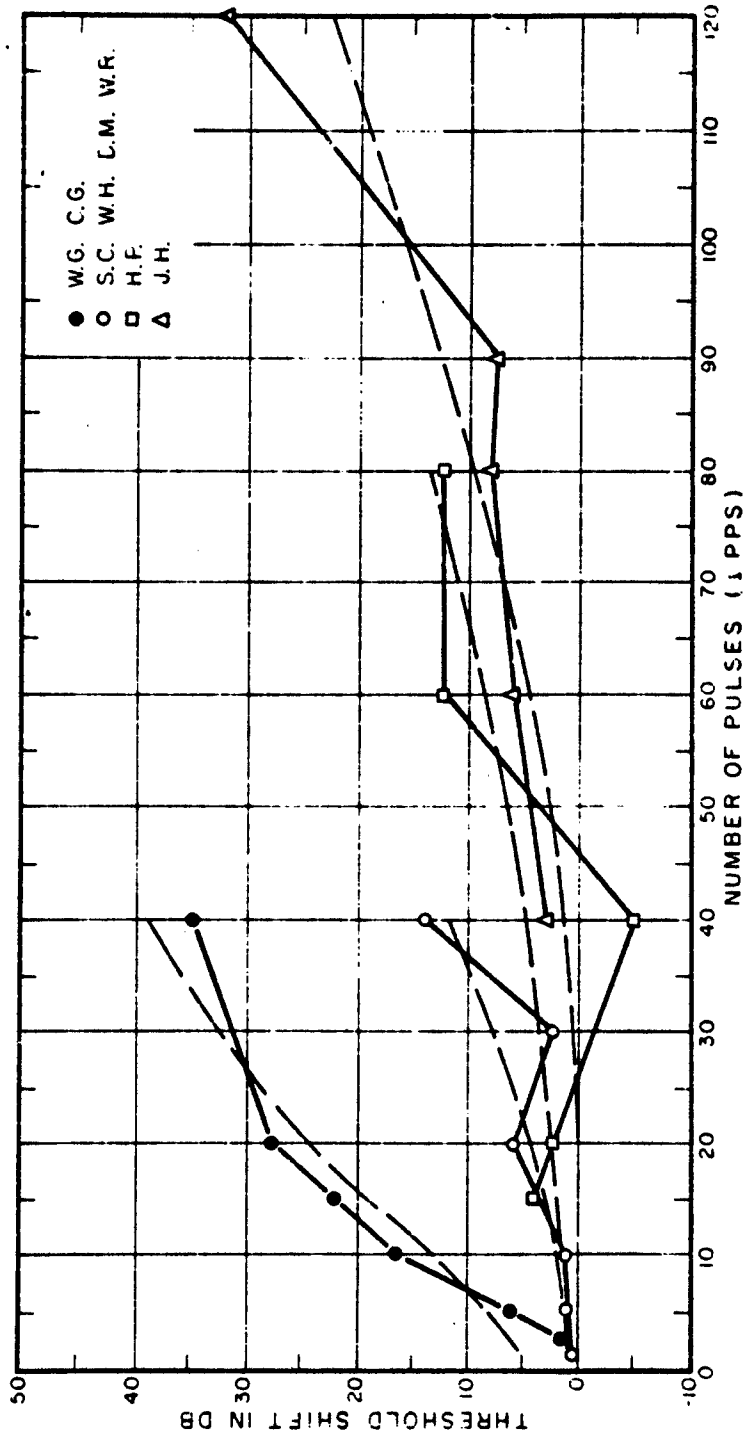
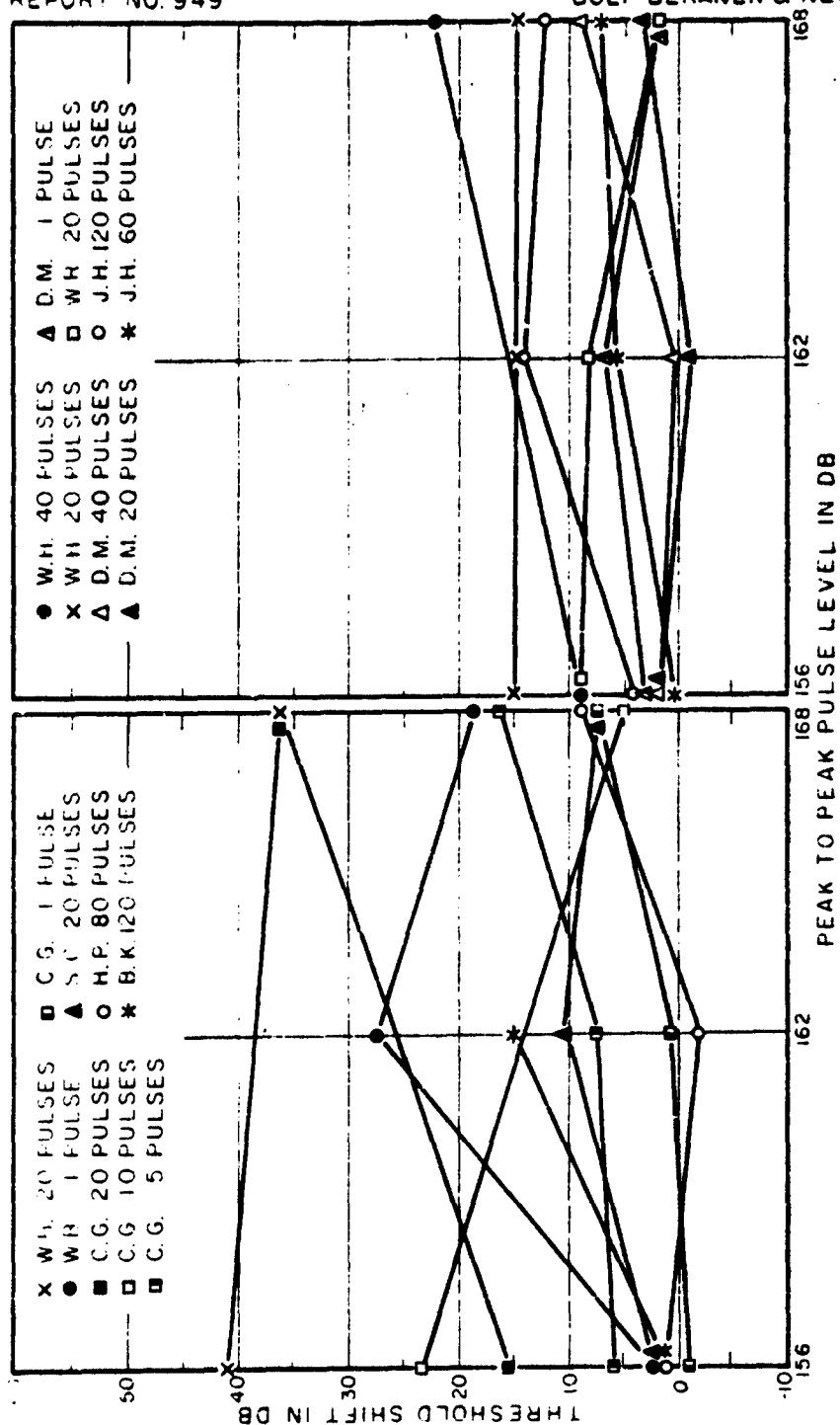FIG. 19   AVERAGE TTS$_2$ AT 4000 AND 4500 CPS.   SMOOTH CURVES ARE HYPO-
THETICAL FUNCTIONS RELATING TTS$_2$ TO NUMBER OF PULSES.
PARAMETER IS THE SUBGROUP OF SUBJECTS.

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FIG. 20 TEMPORARY THRESHOLD SHIFTS AT 2000 CPS TWO MINUTES AFTER
EXPOSURE TO TRIANGULAR ACOUSTIC TRANSIENTS, 156, 162 AND 168 DB
PEAK TO PEAK. PARAMETER IS THE SUBJECT AND NUMBER OF PULSES.
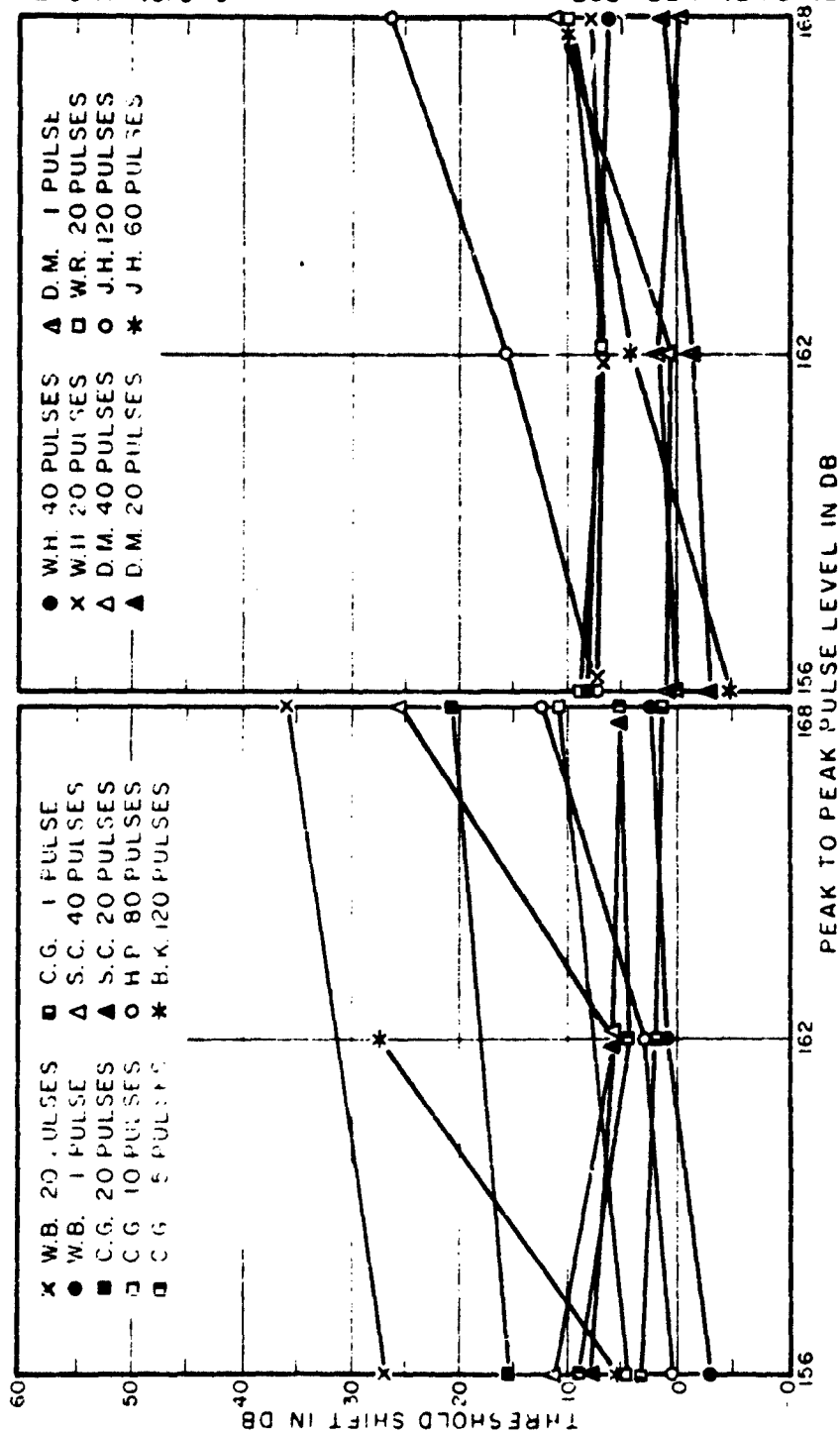REPETITION RATE IS ONE PULSE PER SECOND.

FIG. 21 AVERAGE OF TEMPORARY THRESHOLD SHIFTS AT 4000 AND 4500 CPS TWO
MINUTES AFTER EXPOSURE TO TRIANGULAR ACOUSTIC TRANSIENT, 156, 162
AND 168 DB PEAK TO PEAK. PARAMETER IS THE SUBJECT AND NUMBER OF
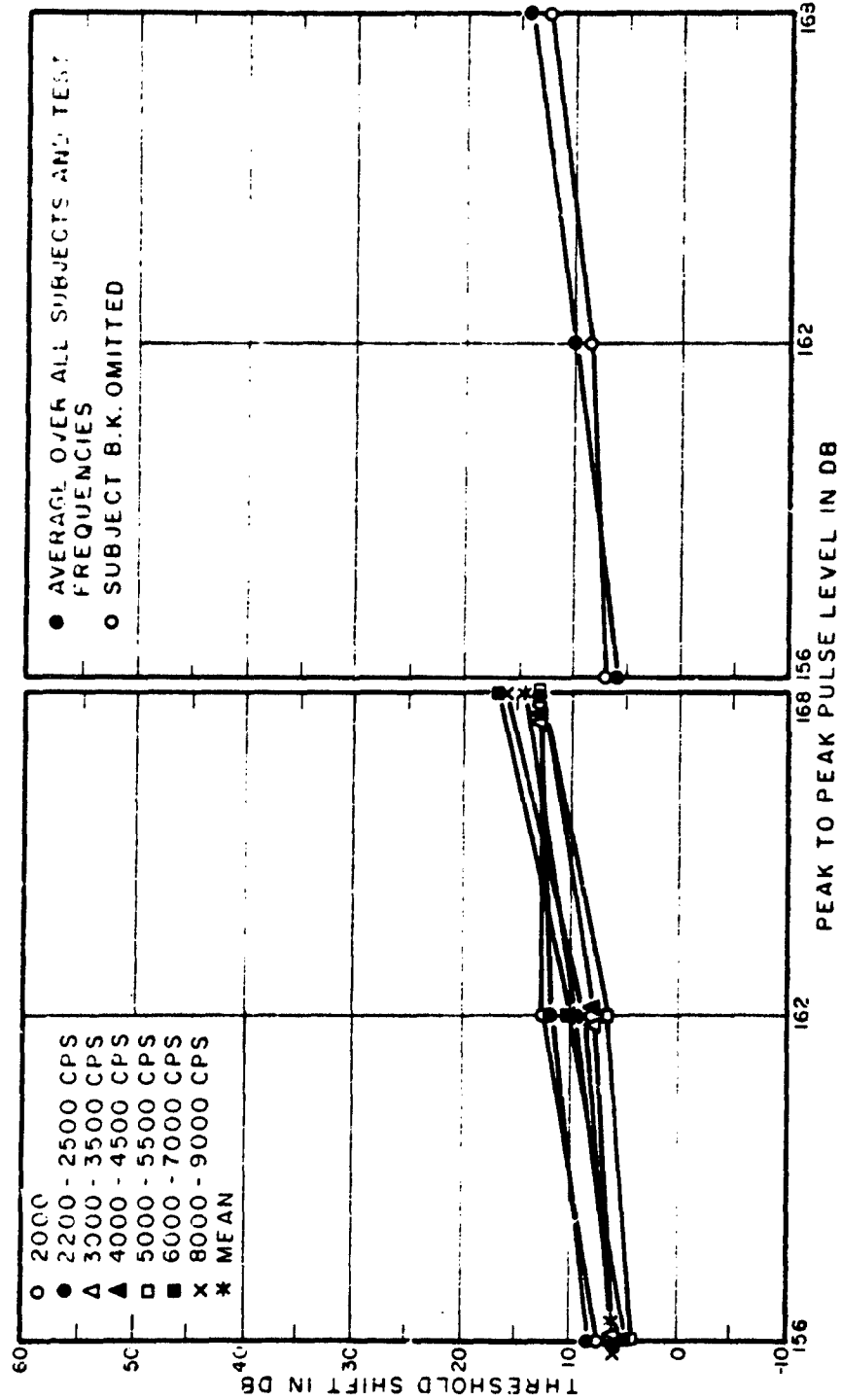PULSES. REPETITION RATE IS ONE PULSE PER SECOND.

FIG. 22 AVERAGE OF TEMPORARY THRESHOLD SHIFTS OVER ALL SUBJECTS TWO MINUTES AFTER EXPOSURE TO TRIANGULAR ACOUSTIC TRANSIENTS, 156, 162 AND 168 DB PEAK TO PEAK. PARAMETER IS THE TEST FREQUENCY.
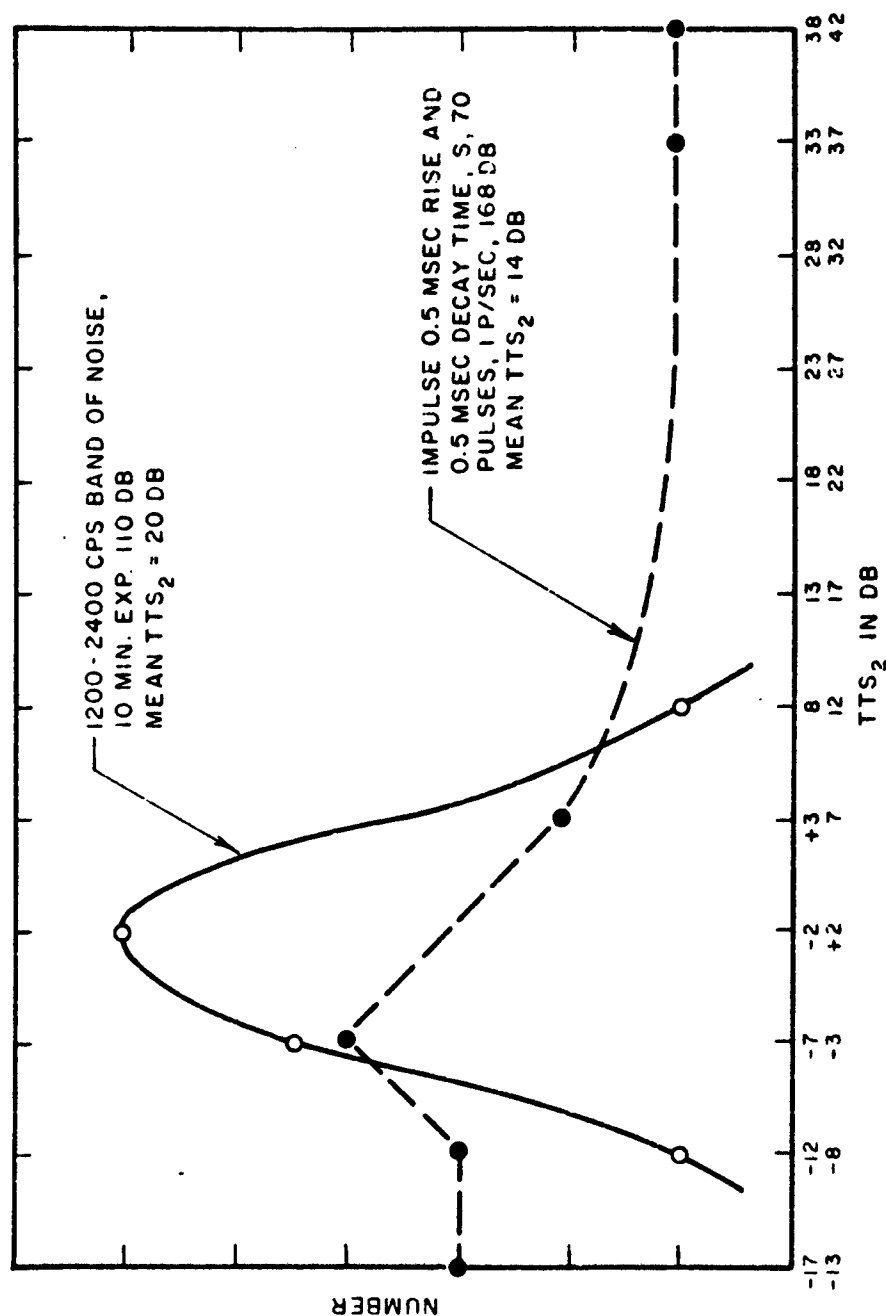
FIG. 23   DISTRIBUTION OF DIFFERENCES BETWEEN MEAN OF DIFFERENCES AND DIFFERENCES BETWEEN PRE AND POST EXPOSURE.   AVERAGE TTS$_2$ AT 2000 AND 4000 CPS.

MEAN = -1.2 DB
σ = 1.4 DB
N = 18

DIFFERENCE IN DB BETWEEN 1ST PRE-EXPOSURE AND
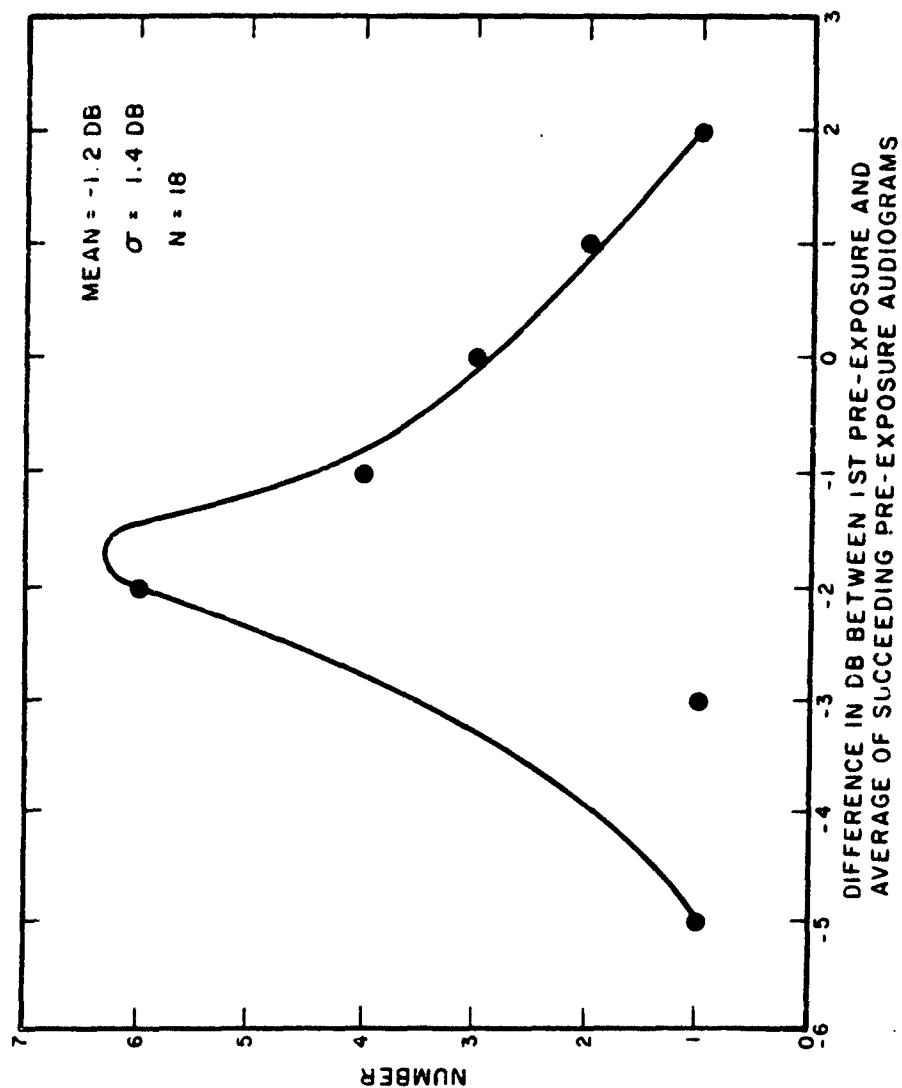AVERAGE OF SUCCEEDING PRE-EXPOSURE AUDIOGRAMS

NUMBER

FIG. 24 MEAN OF AVERAGE DIFFERENCES AT 2000-4000 CPS
BETWEEN 1ST PRE-EXPOSURE AUDIOGRAM AND SUCCEEDING
PRE-EXPOSURE AUDIOGRAMS FOR EACH SUBJECT